First cosmological results from Planck

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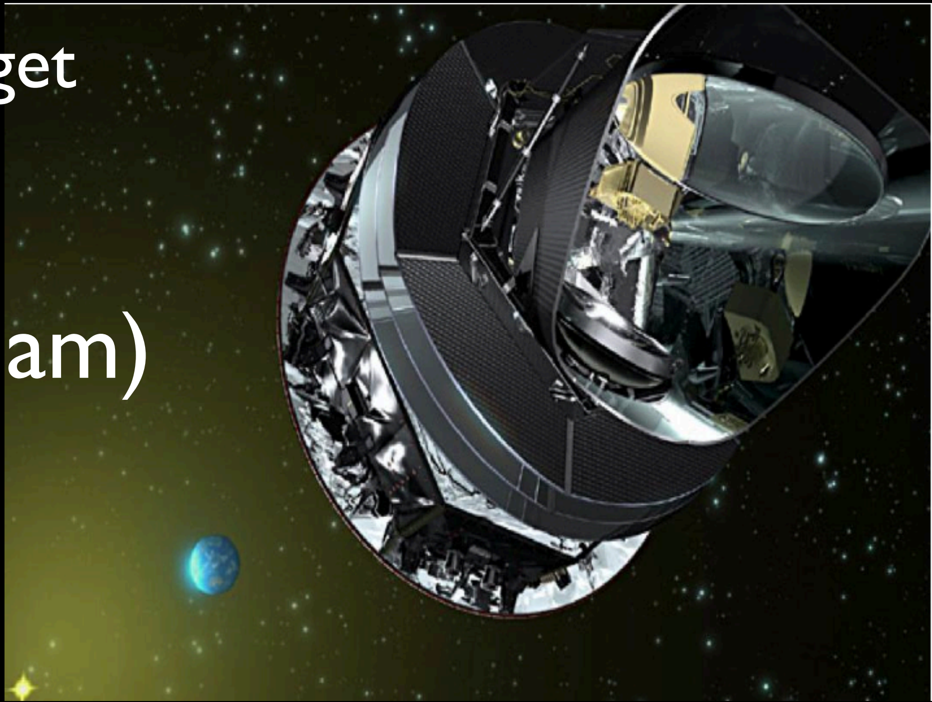
based on talks given by Jean-Loup Puget

ICISE 2013 – Quy Nhon (Vietnam)



Outline

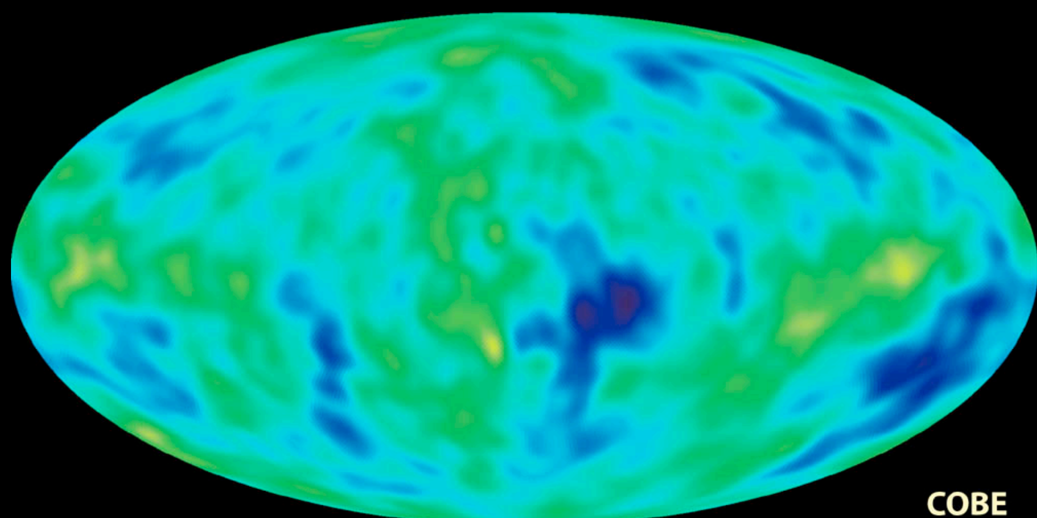
- The Planck instrument
- Angular spectral power
- Cosmological parameters
- CMB lensing and neutrino mass
- Probing inflation
- Polarization

Brief history of space CMB observations

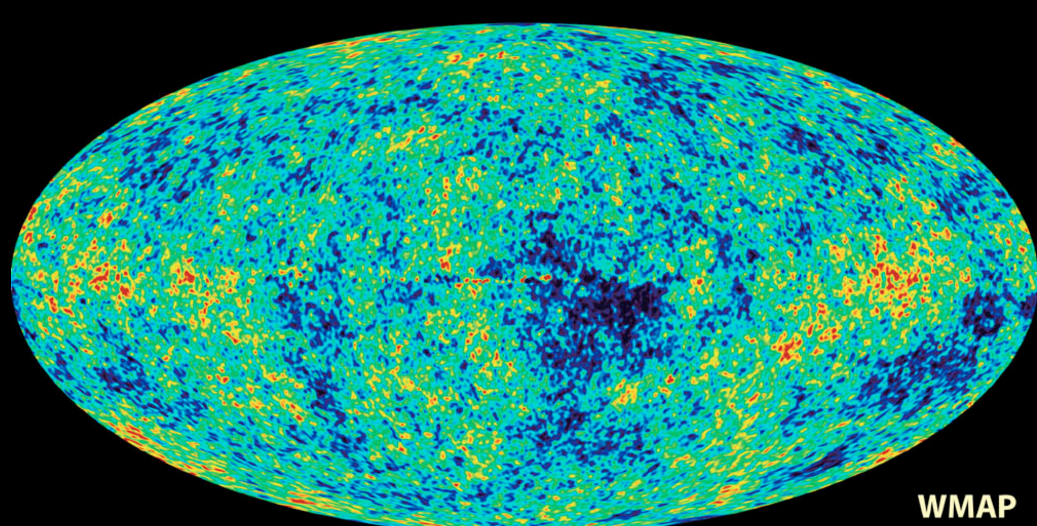
- balloon borne + 3 generations of space CMB experiments
  - ➢ COBE (1990) Planck spectrum, first detection of anisotropies (1992)
  - ➢ Balloon borne exp Boomerang, MAXIMA, ARCHEOPS (2000,2001)
  - ➢ WMAP 2003-2012
  - ➢ Planck (launched in 2009) 2011 (Early results on foreground),
  - ➢ Planck 2013: Cosmological results based on temperature and nominal mission (2 sky surveys)
  - ➢ 28 papers (4 others coming) , 850 pages, ~240 authors/paper
    - ✓ Planck collaboration 620 scientists, in 100 institutes, 17 countries
  - ➢ Future: Planck 2014 Cosmological results with the full mission
    - ✓ (5 HFI surveys, 8 LFI surveys) including polarization
- many ground based experiments ongoing (ACT, SPT, QUIET, QUBIC, …) and balloon borne (SPIDER, EBEX,…)

Measures of the CMB anisotropies

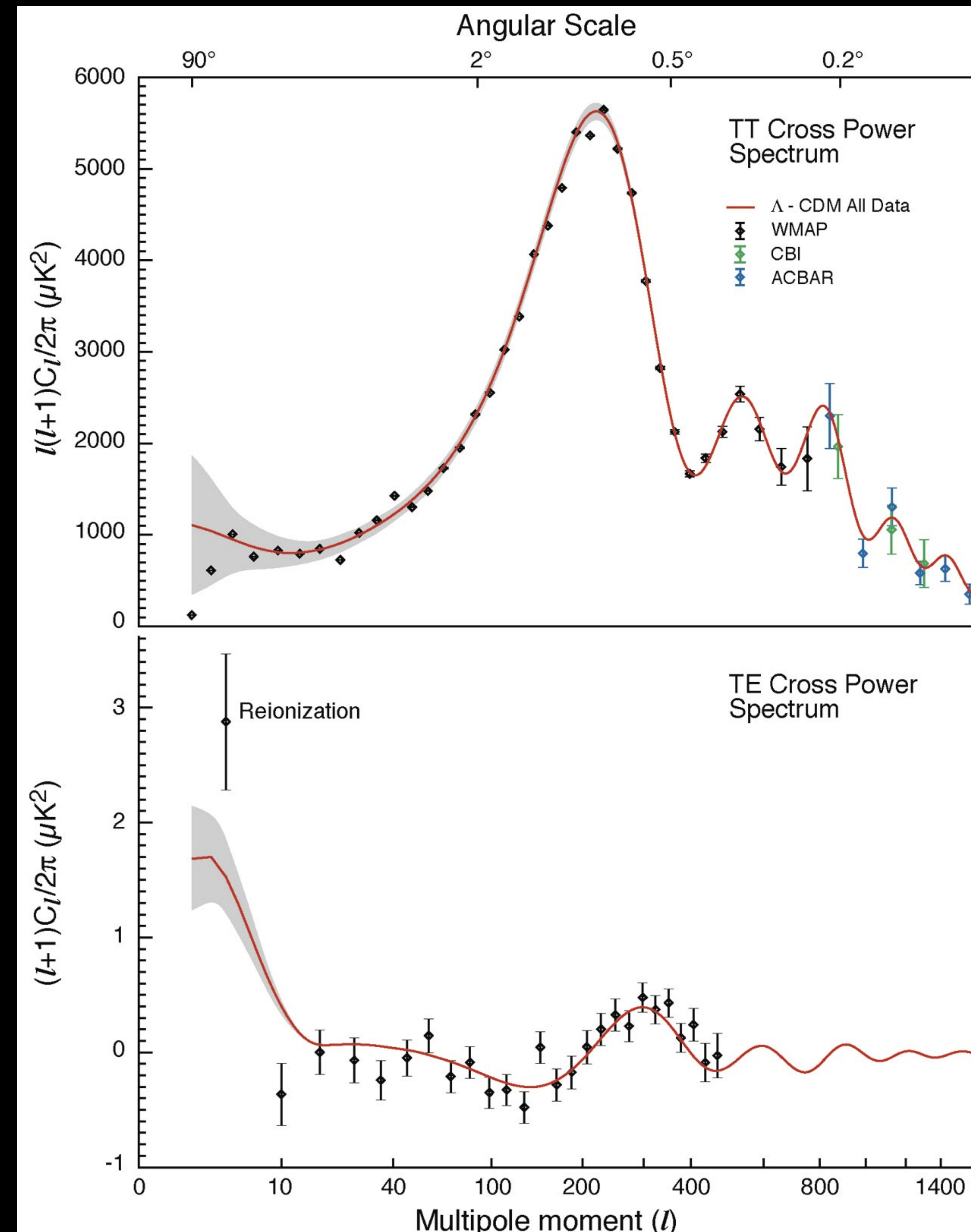
- **DMR-COBE first detection of the large scale anisotropies (Smoot et al 1992)**
- **first clear detection of the first acoustic peak: Boomerang MAXIMA and Archeops (De Bernardis et al 2000 , A. Lange et al 2001, Hanany et al 2000, Benoît et al 2002)**
- **WMAP map and power spectrum (2003)**



COBE



WMAP



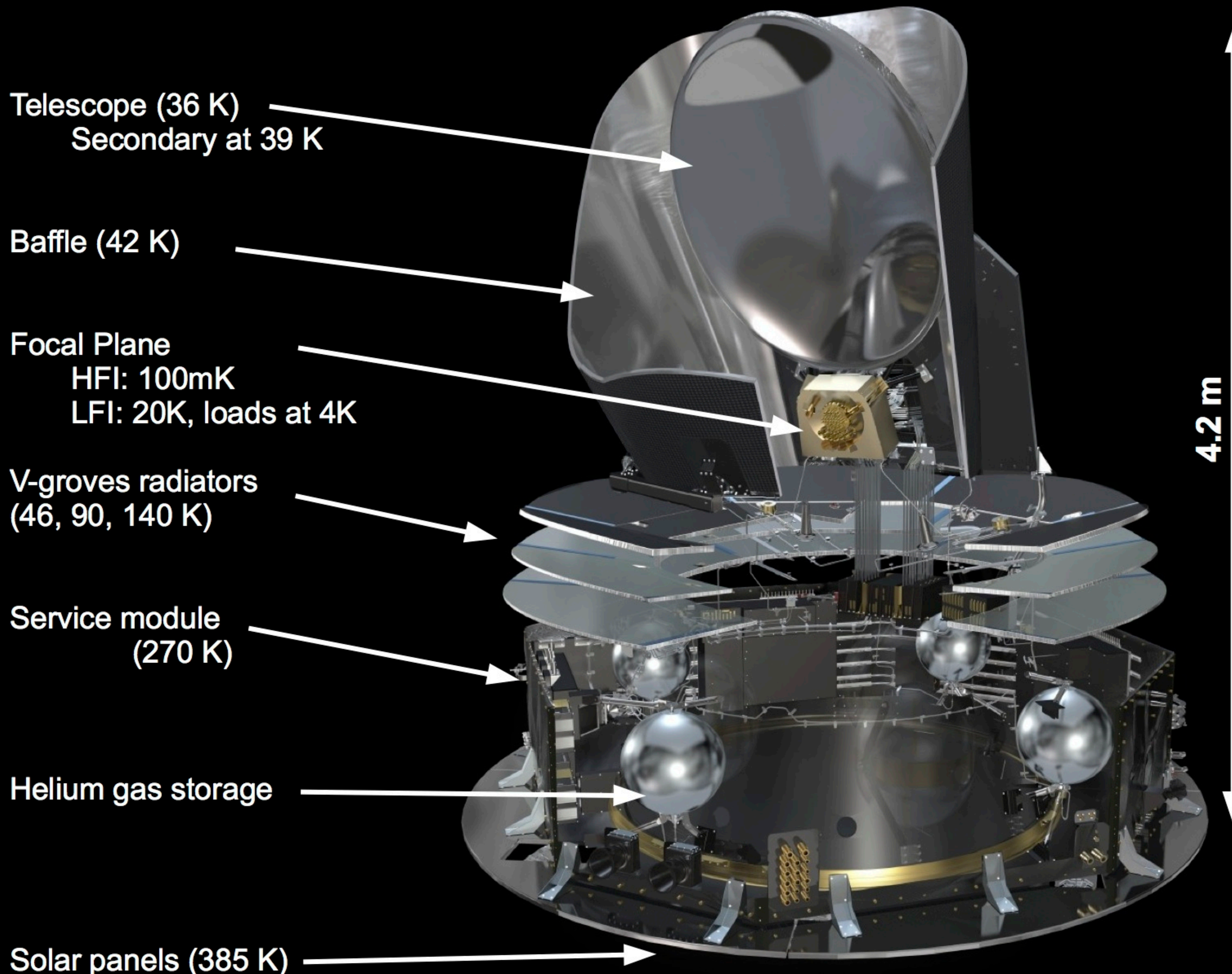
Planck goals in 1996

- Planck (like WMAP) aimed at a much better determination of the "concordance model" parameters through measurements of the power spectrum up to 7 acoustic peaks (remove some degeneracies)

- it also aimed at measuring the lensing of the CMB by LSS (Large Scale Structures) with high accuracy

- detecting or putting upper limits on non-gaussianity and limits on neutrino physics

- measuring the polarization with high signal to noise (4 acoustic peaks in EE, detection or low upper limit on tensor to scalar ratio down to 5%)


Telescope (36 K)
Secondary at 39 K
Baffle (42 K)
Focal Plane
HFI: 100mK
LFI: 20K, loads at 4K
V-groves radiators
(46, 90, 140 K)
Service module
(270 K)
Helium gas storage
Solar panels (385 K)
4.2 m

Planck breakthroughs in 2009

- Technological performance never achieved in space before :
  - sensitive and fast bolometers for HFI
    - ✓ NEP $< 2.10^{-17}$ W/Hz$^{1/2}$, time constant ~ 5 ms (requires cooling at 100 mK)
    - ✓ low noise electronics : 6 nV/Hz$^{1/2}$, from 10 mHz to 100 Hz
    - ✓ excellent temperature stability from 10 mHz to 100 Hz
  - low noise HEMT amplifier for LFI
- low emissivity, very low side-lobes telescope
- minimum warm surface in front of detectors
- complex cryogenic cooling chain : 50 K (passive) + 20K, 4K, 0.1K active coolers
- Integration of 3 complex chains - electronic, optics, cryogenics

Multiwave-length survey

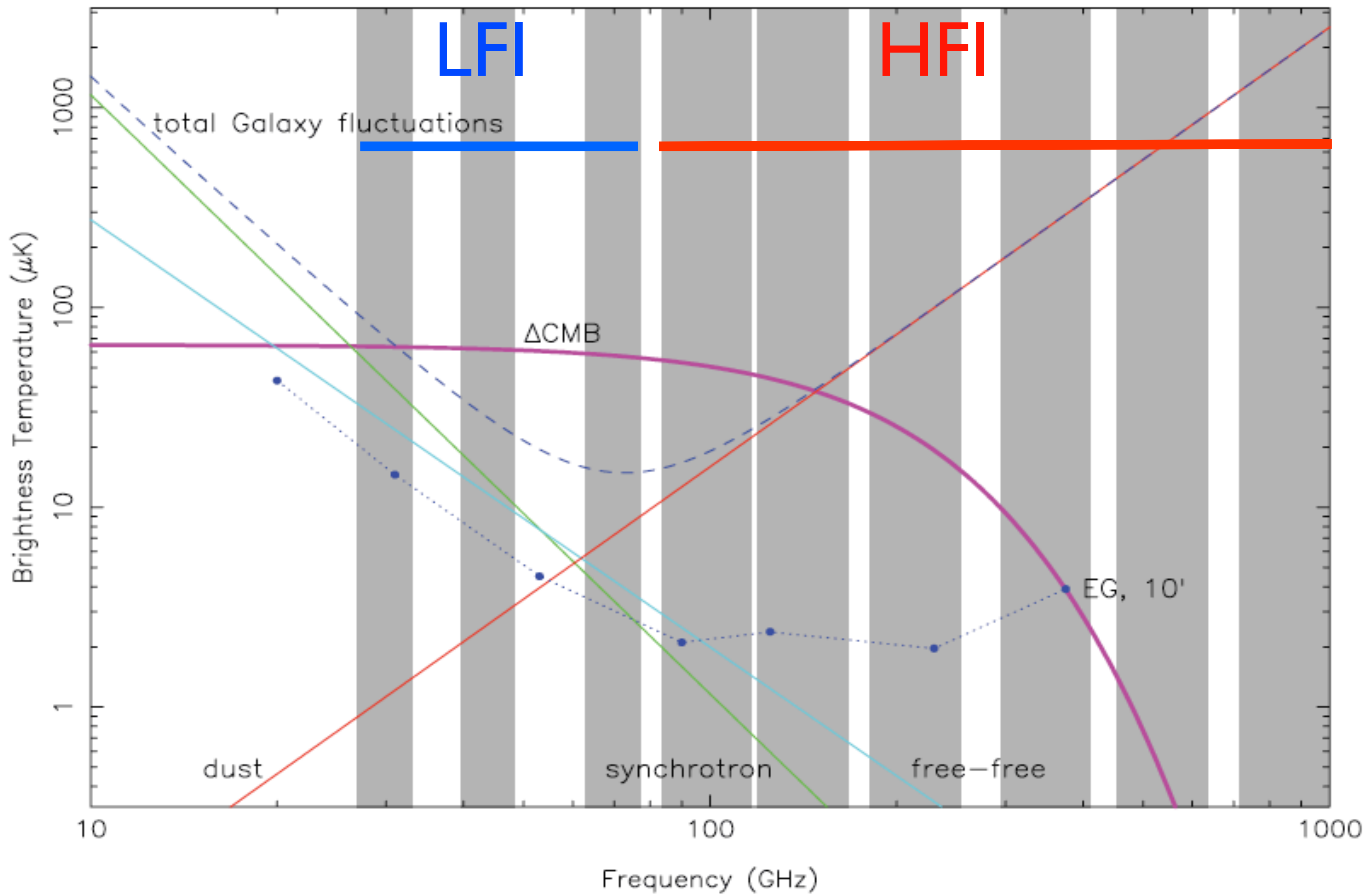
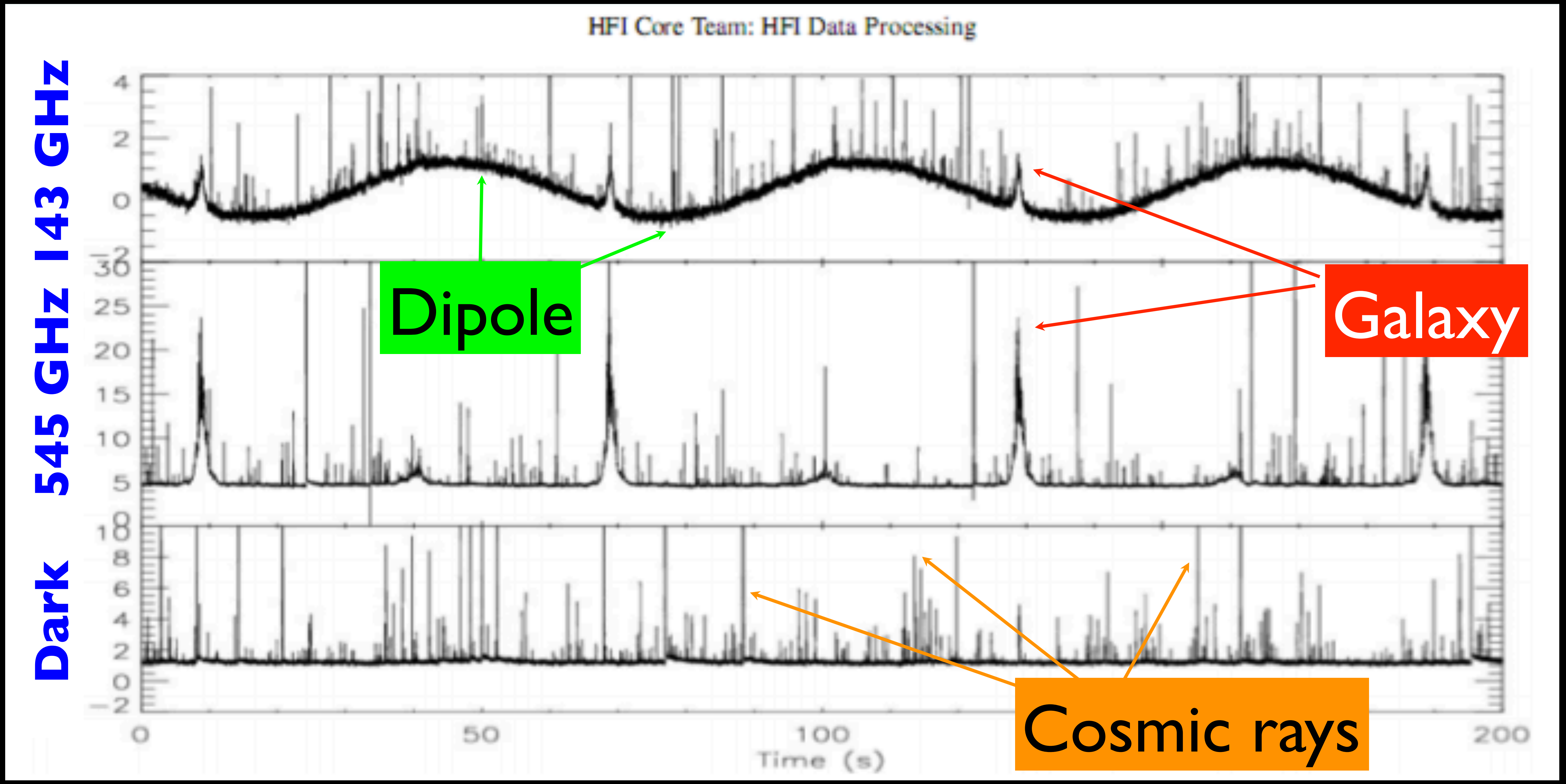
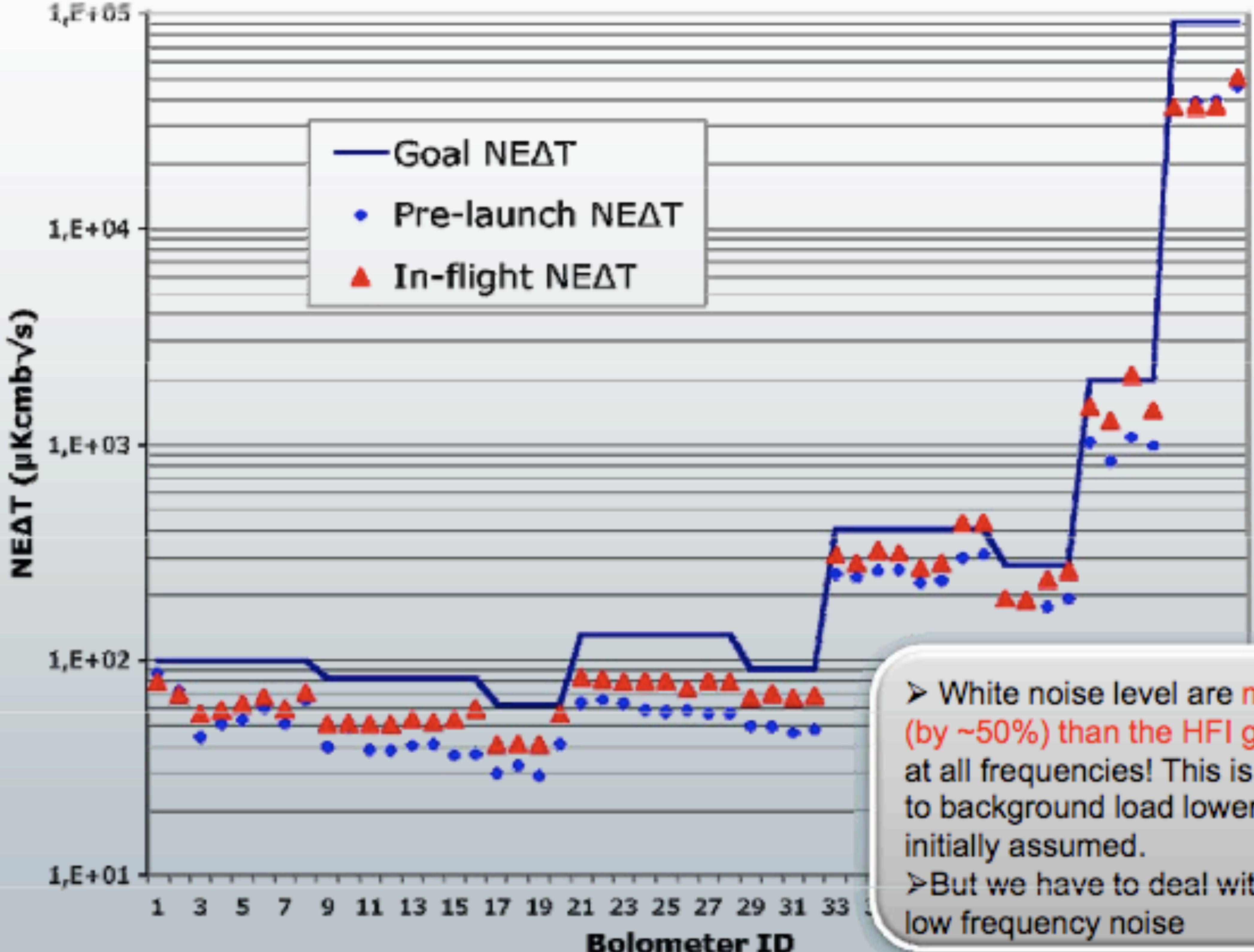


FIG 1.3.— Spectrum of the CMB, and the frequency coverage of the *Planck* channels. Also indicated are the spectra of other sources of fluctuations in the microwave sky. Dust, synchrotron, and free-free temperature fluctuation (i.e., unpolarized) levels correspond to the *WMAP* Kp2 levels (85% of the sky; Bennett et al. 2003). The CMB and Galactic fluctuation levels depend on angular scale, and are shown for $\sim 1^\circ$. On small angular scales, extragalactic sources dominate. The minimum in diffuse foregrounds and the clearest window on CMB fluctuations occurs near 70 GHz. The highest HFI frequencies are primarily sensitive to dust.

3 min of demodulated raw data

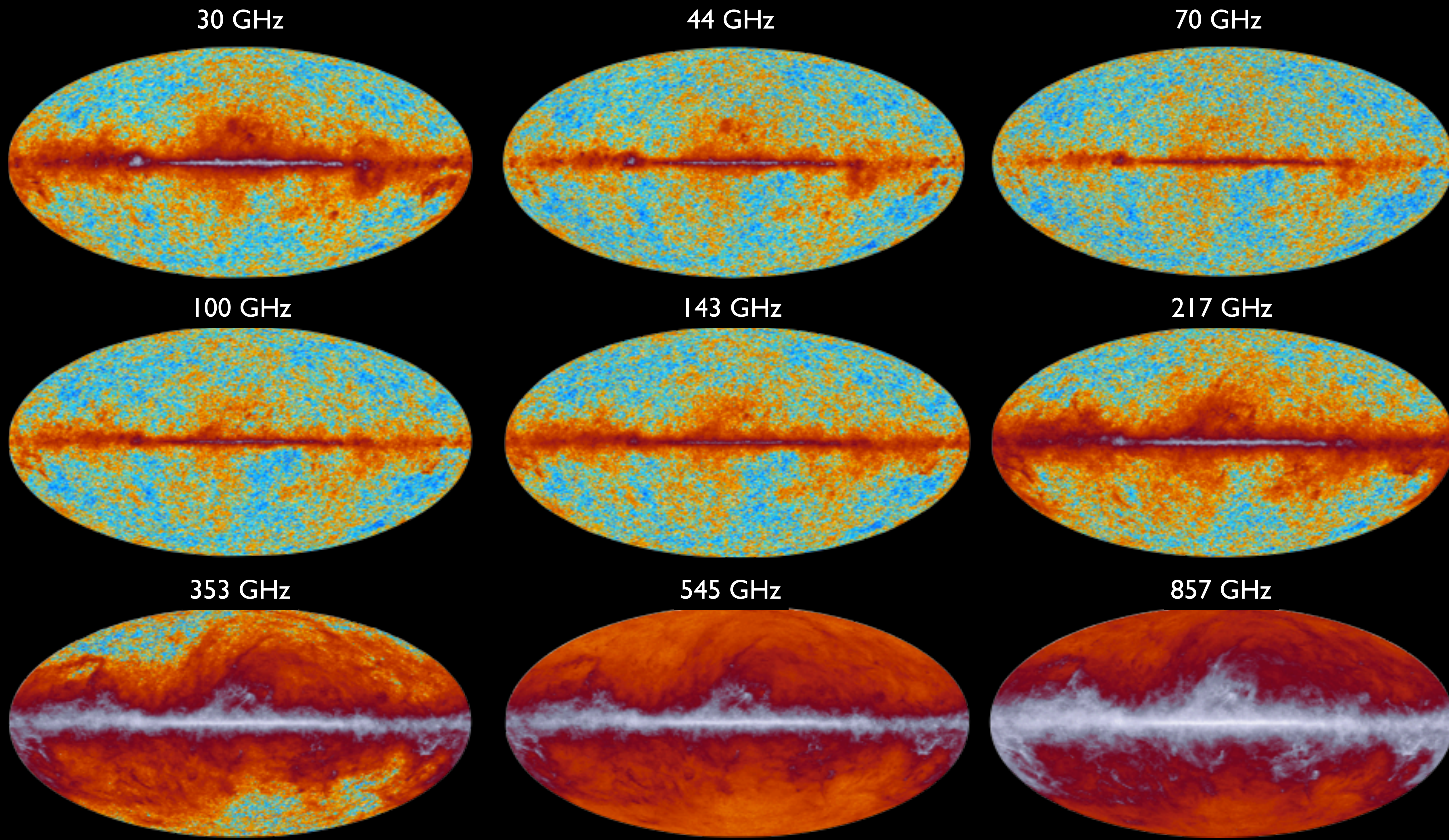


TOI white noise level

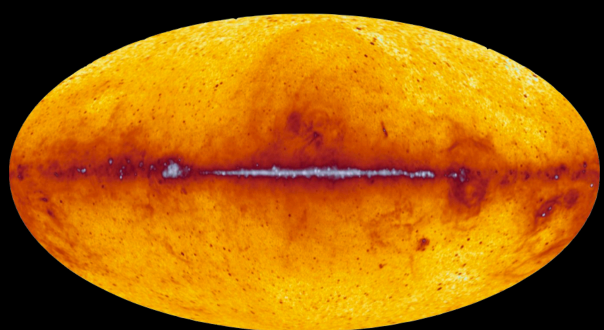


- White noise level are much better (by ~50%) than the HFI goal values at all frequencies! This is mostly due to background load lower than initially assumed.
- But we have to deal with excess low frequency noise

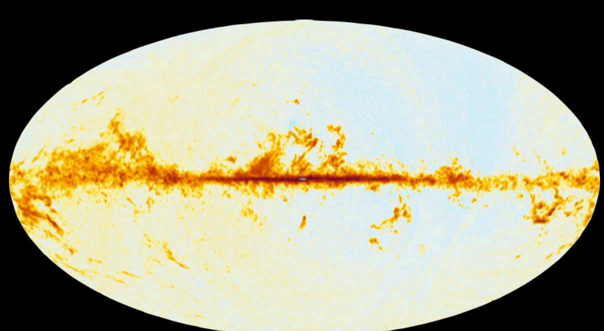
Sky as seen by Planck



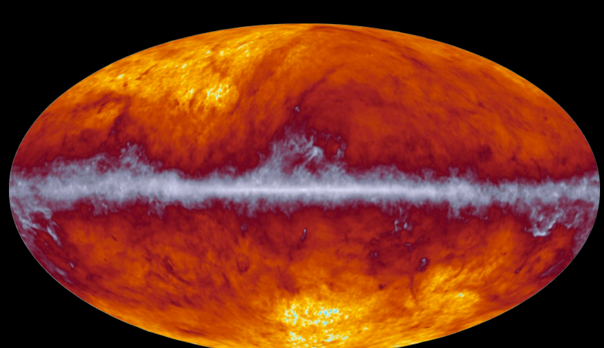
Combinations of the 9 Planck channels allow us to separate the signals into CMB, CO, Dust and other astrophysical components



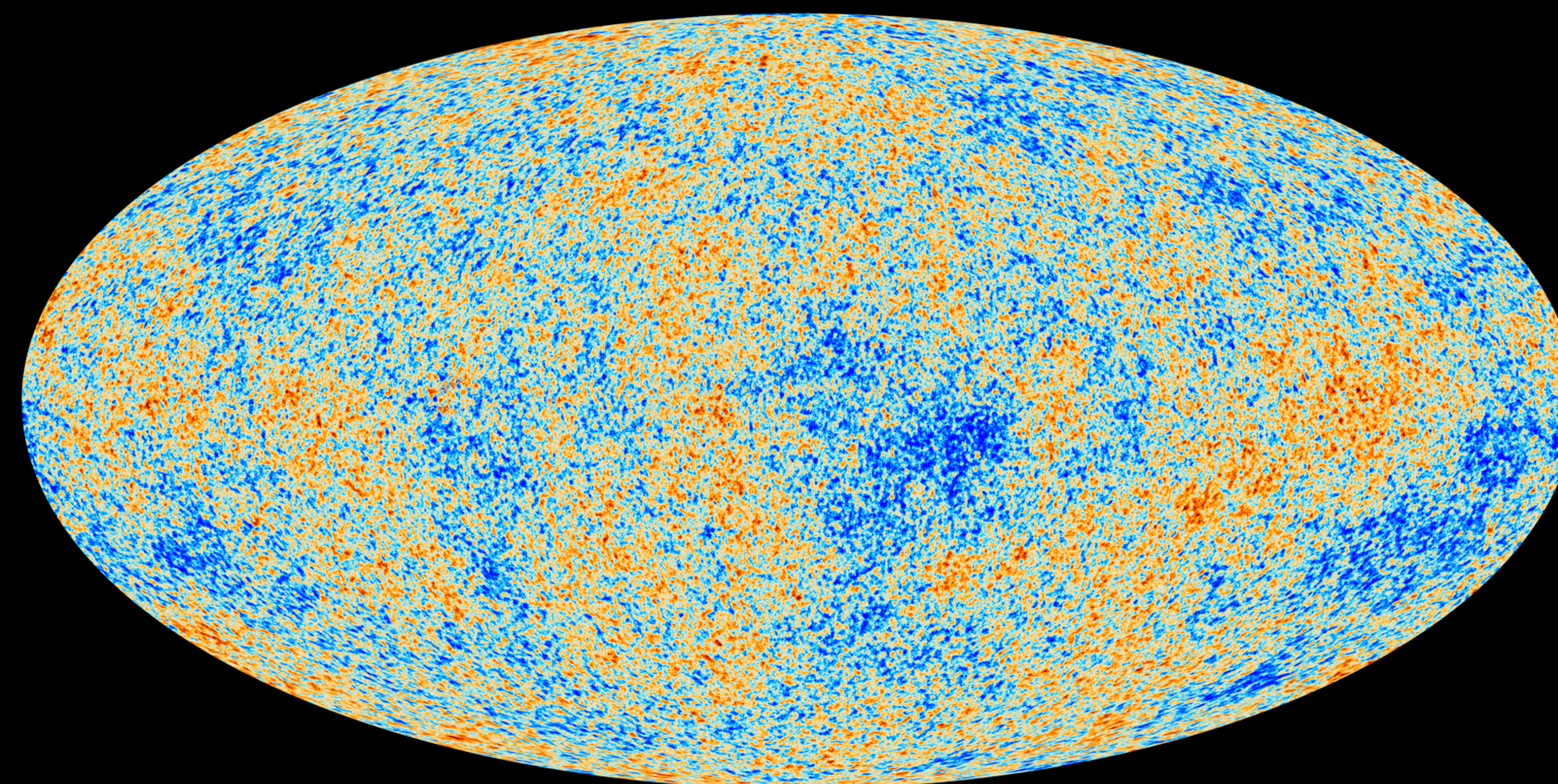
"Radio"



CO map

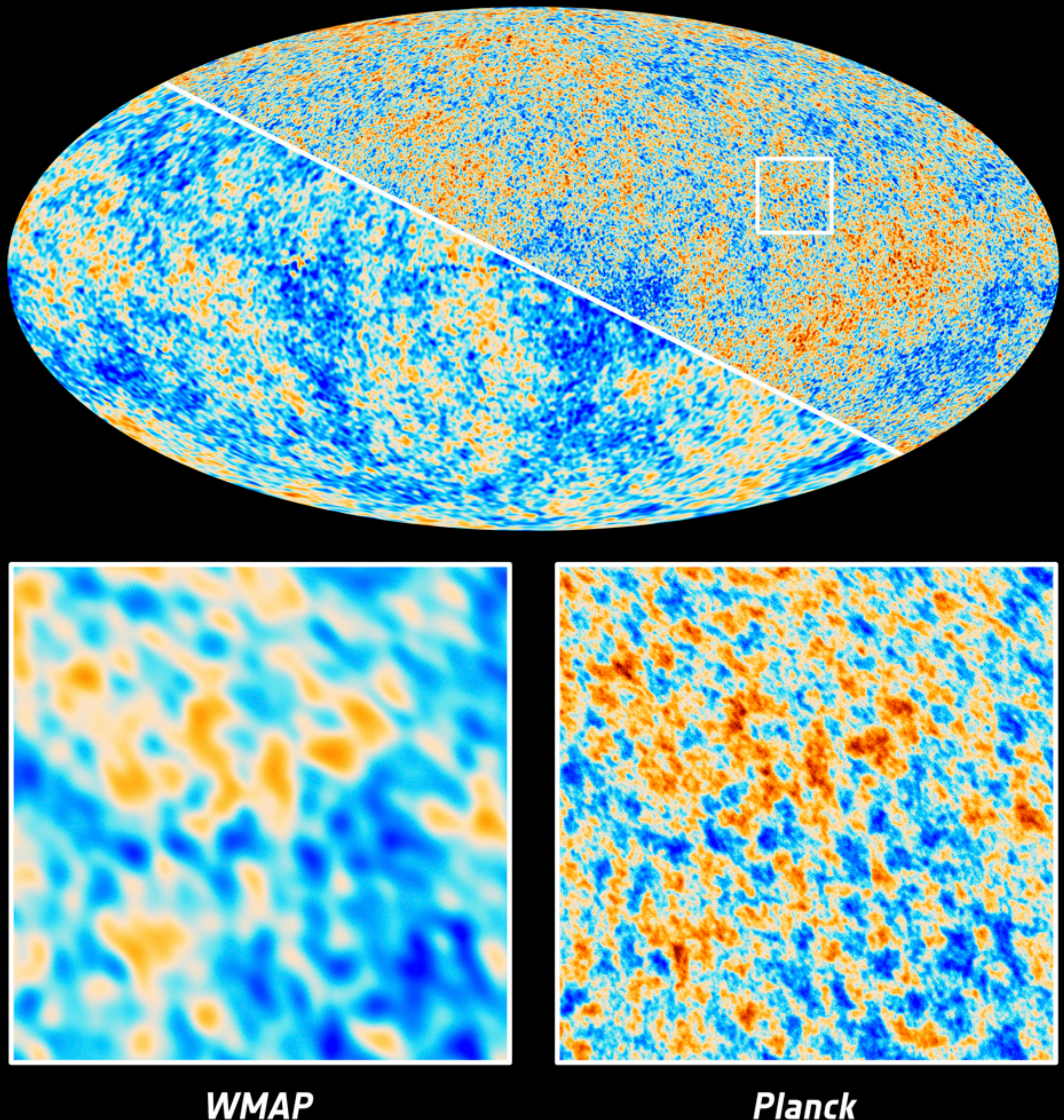


Dust

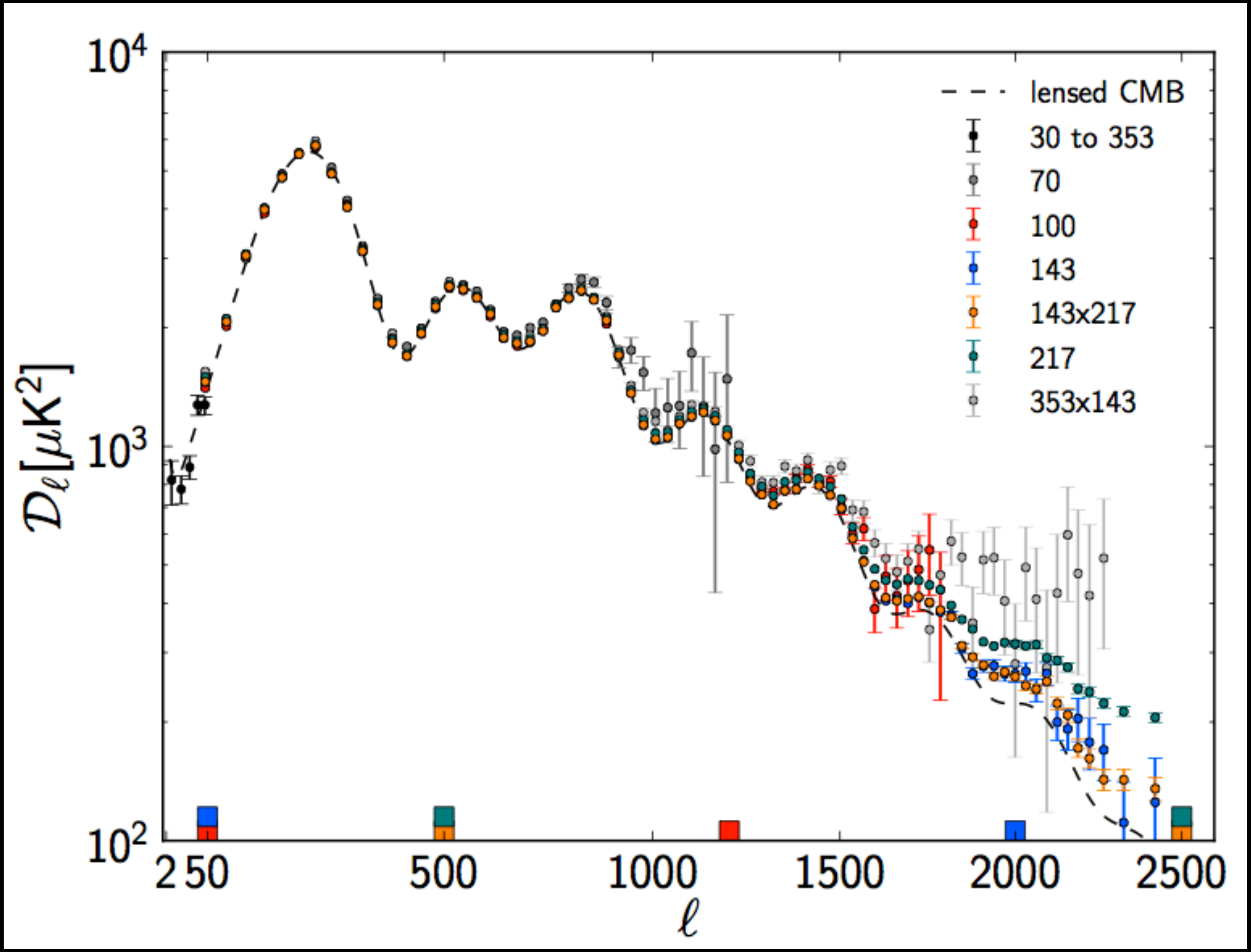


Planck CMB map

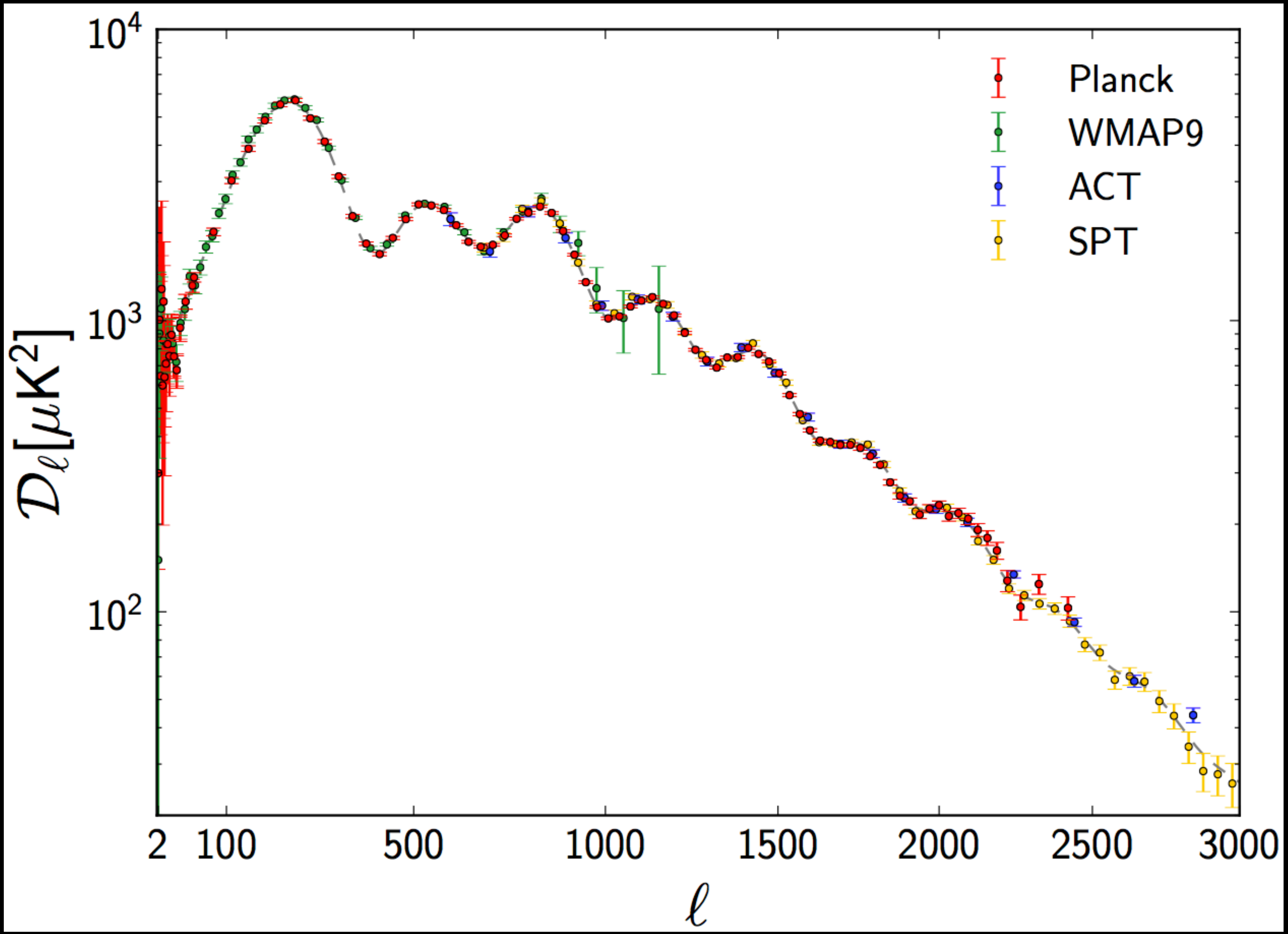
The Cosmic Microwave Background as seen by Planck and WMAP



Planck pre-foreground removal power spectra



Foreground-removal power spectra
comparison with other experiments



Cosmological parameters

Planck with temperature only + WMAP polarization for τ

Λ-CDM with only 6 free parameters

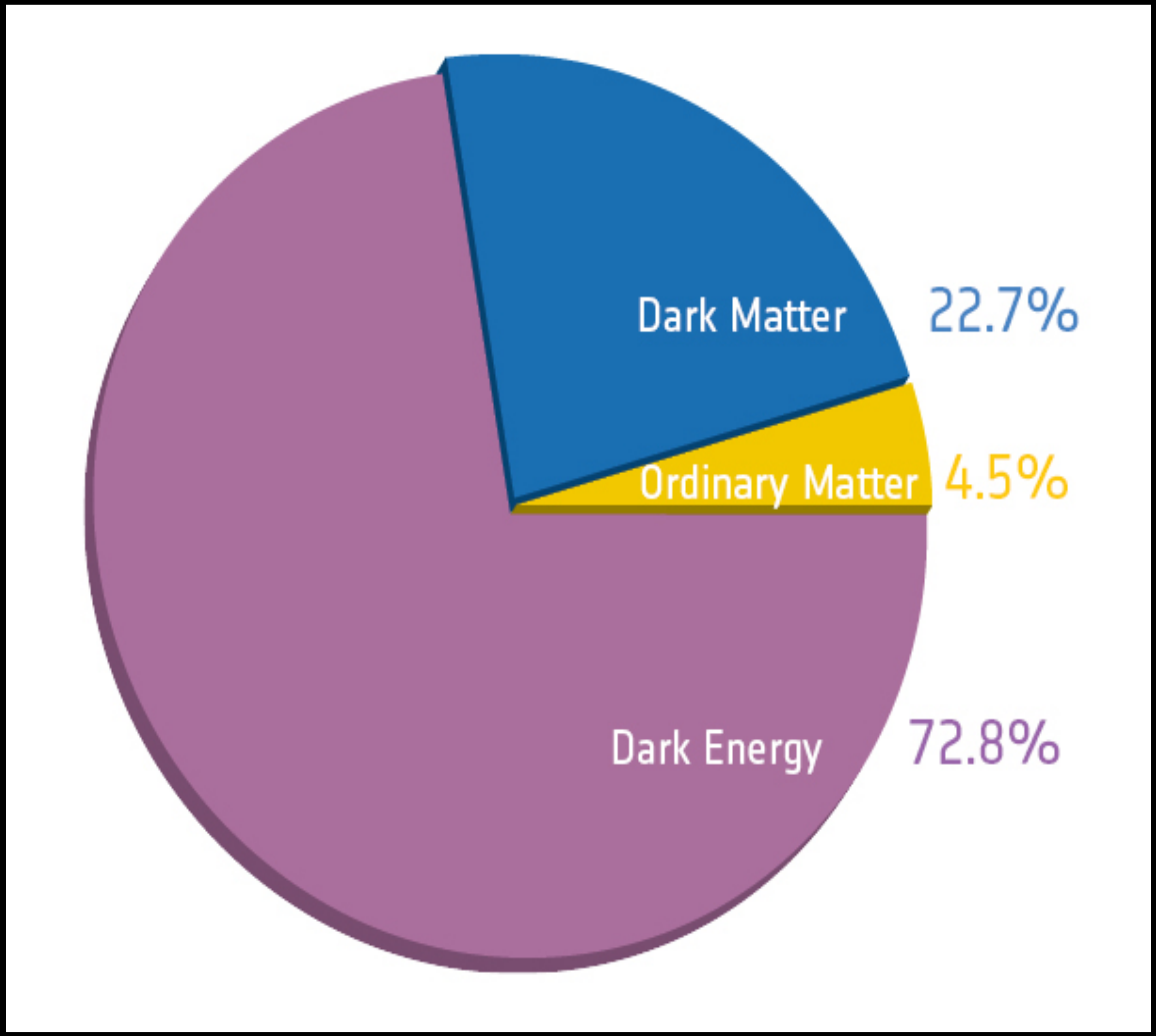
BASE ΛCDM MODEL

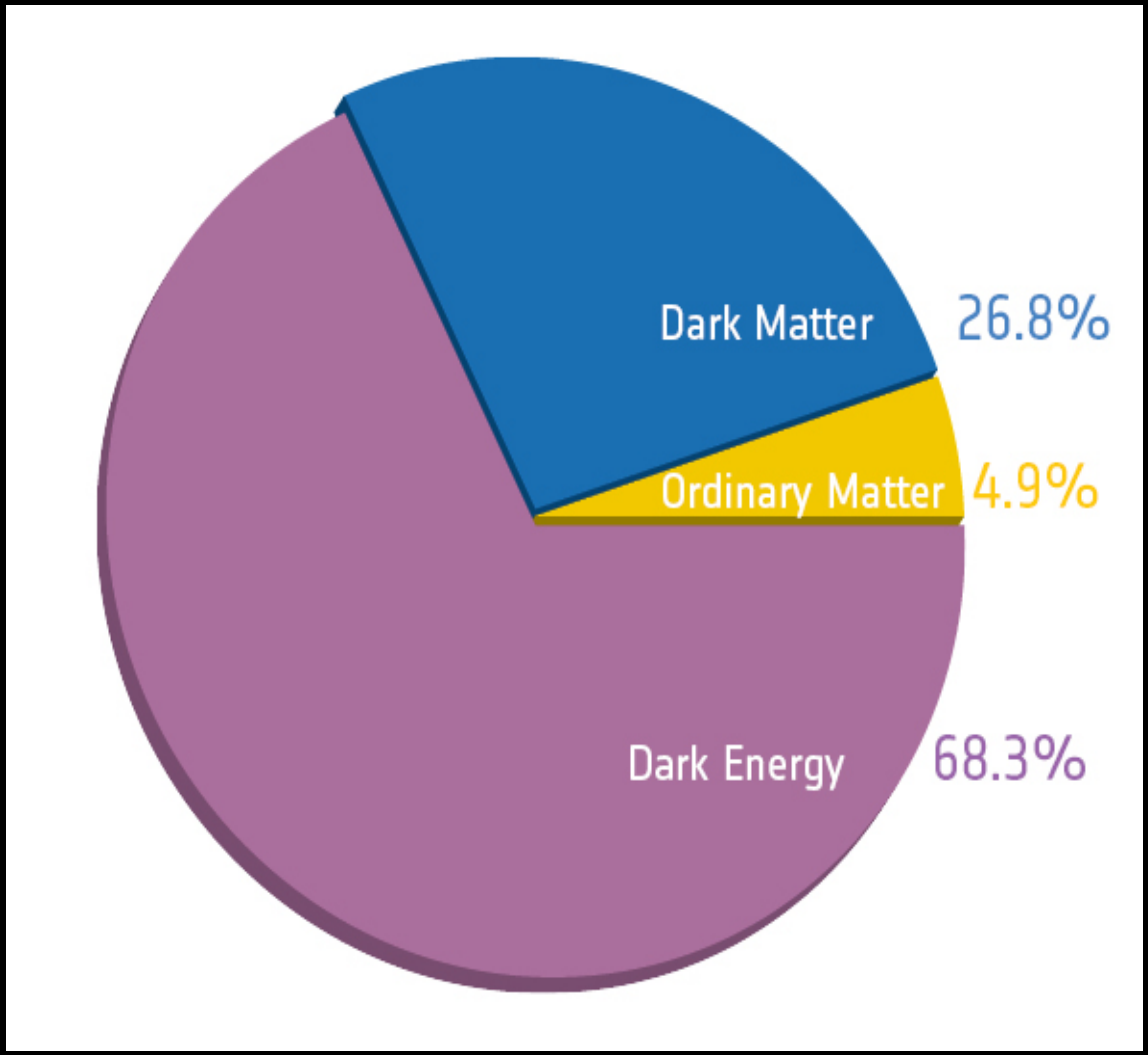
Parameter	Value (68%)
$\Omega_b h^2$	0.02207±0.00027
$\Omega_c h^2$	0.1198±0.0026
$100\theta_*$	1.04148±0.00062
τ	0.091±0.014
n_s	0.9585±0.0070
H_0	67.3±1.2
Ω_Λ	0.685±0.017
σ_8	0.828±0.012
z_{re}	11.1±1.1

- note 6 10^{-4} error bar
- scale invariance excluded at 6 σ (as predicted by inflation models)
- note accuracy 1.8%

First cosmological results from Planck

The cosmic recipe

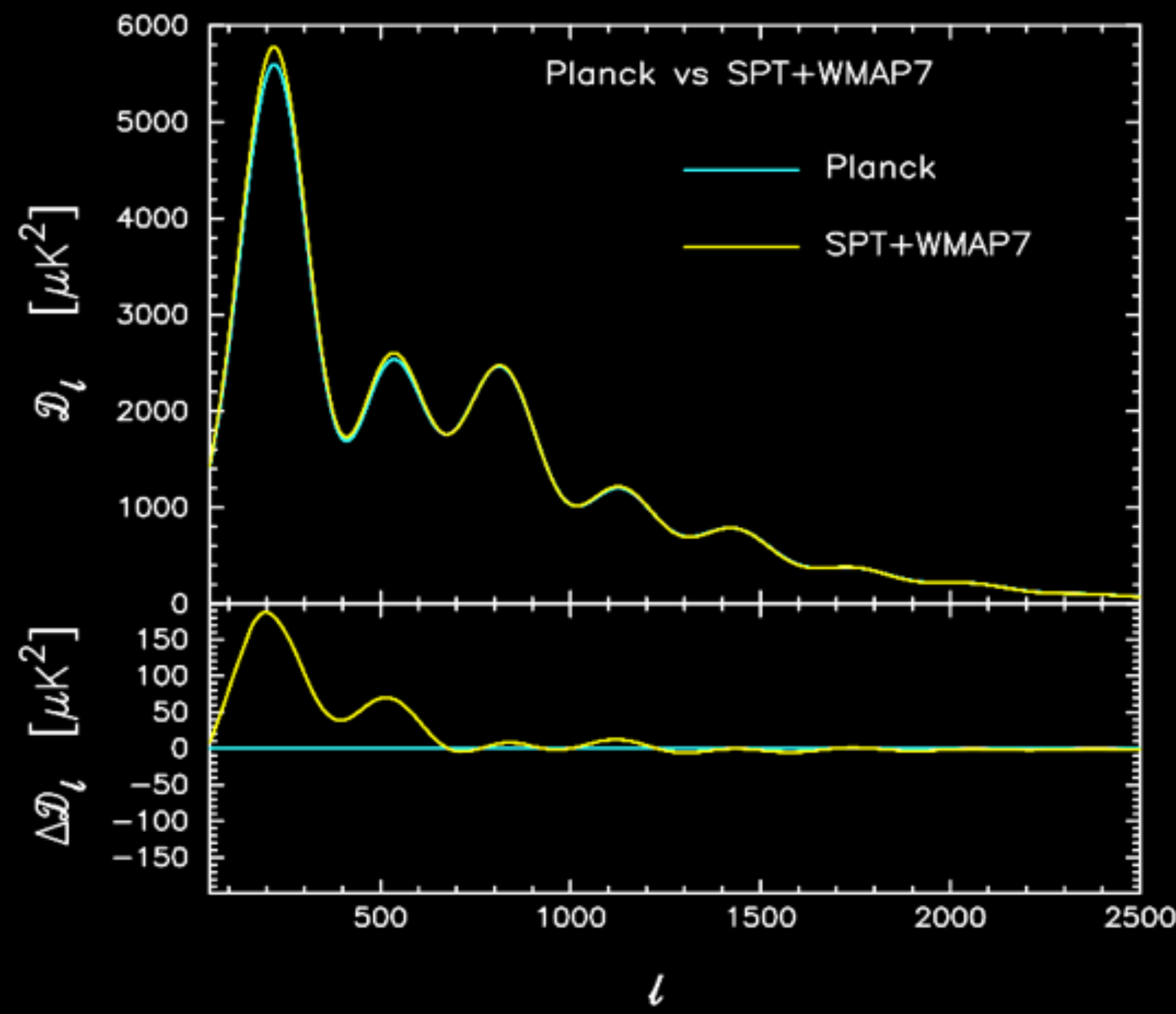




BEFORE PLANCK

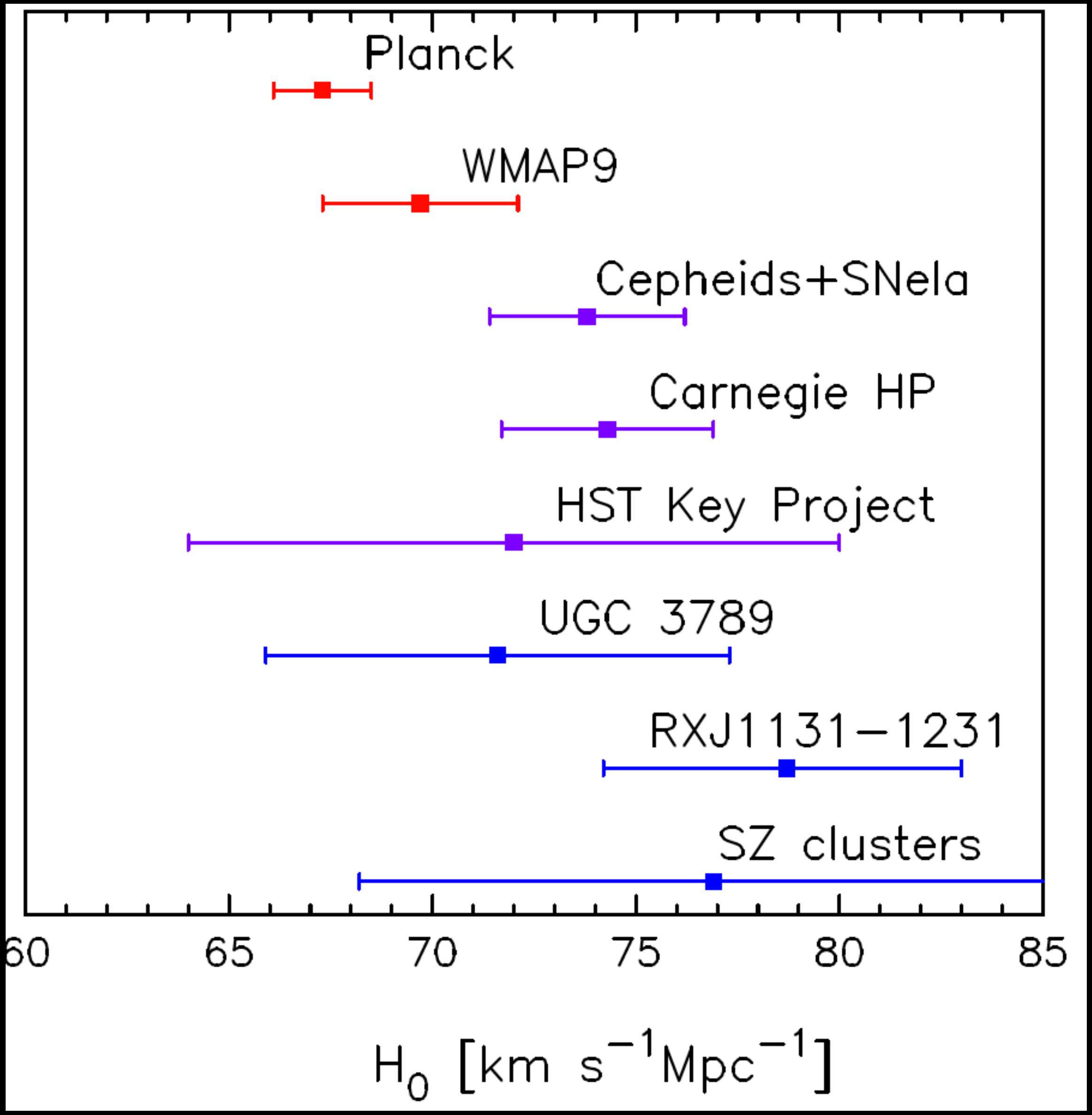
AFTER PLANCK

Comparison between Planck and WMAP temperature spectra

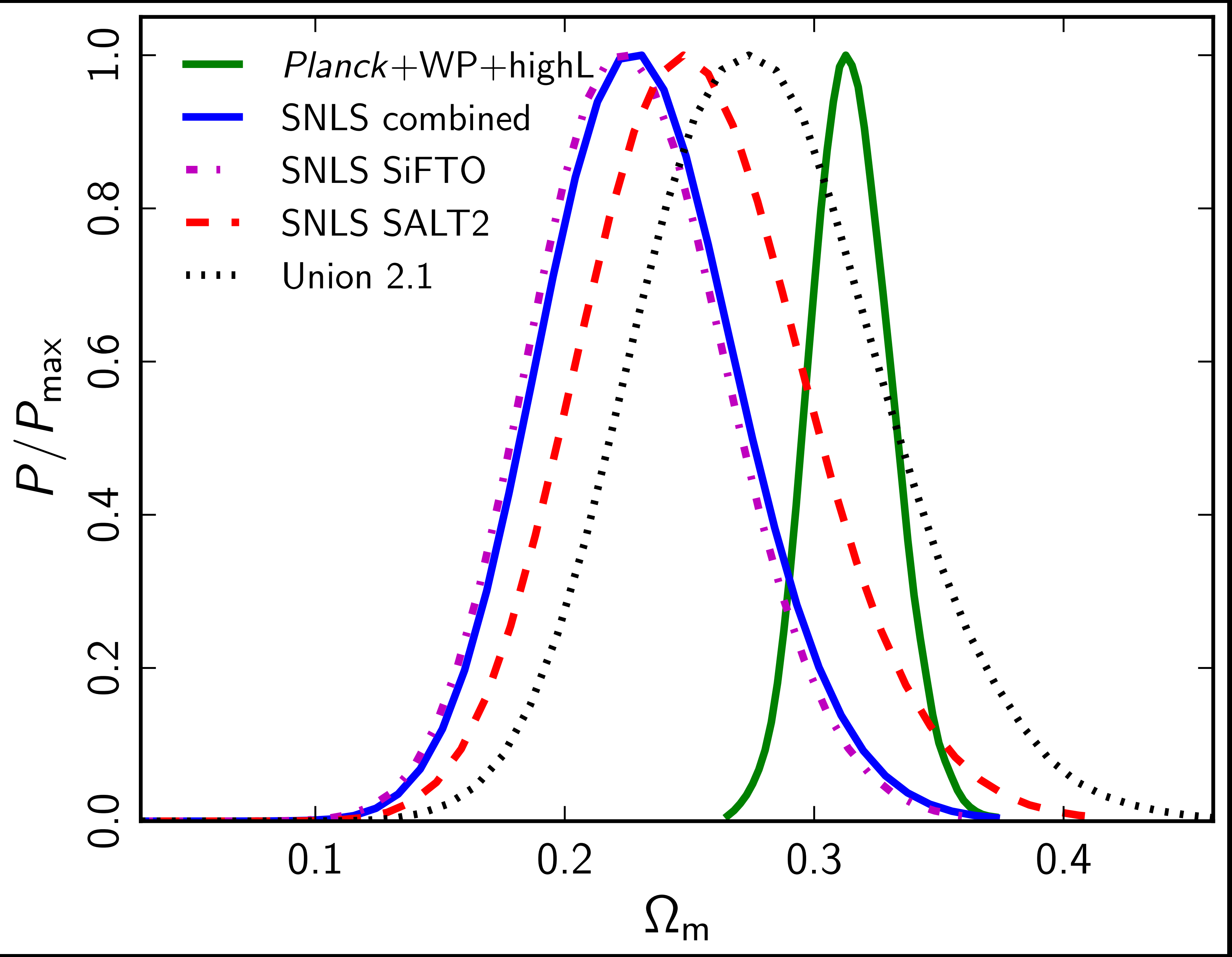


Expansion rate (Hubble constant)

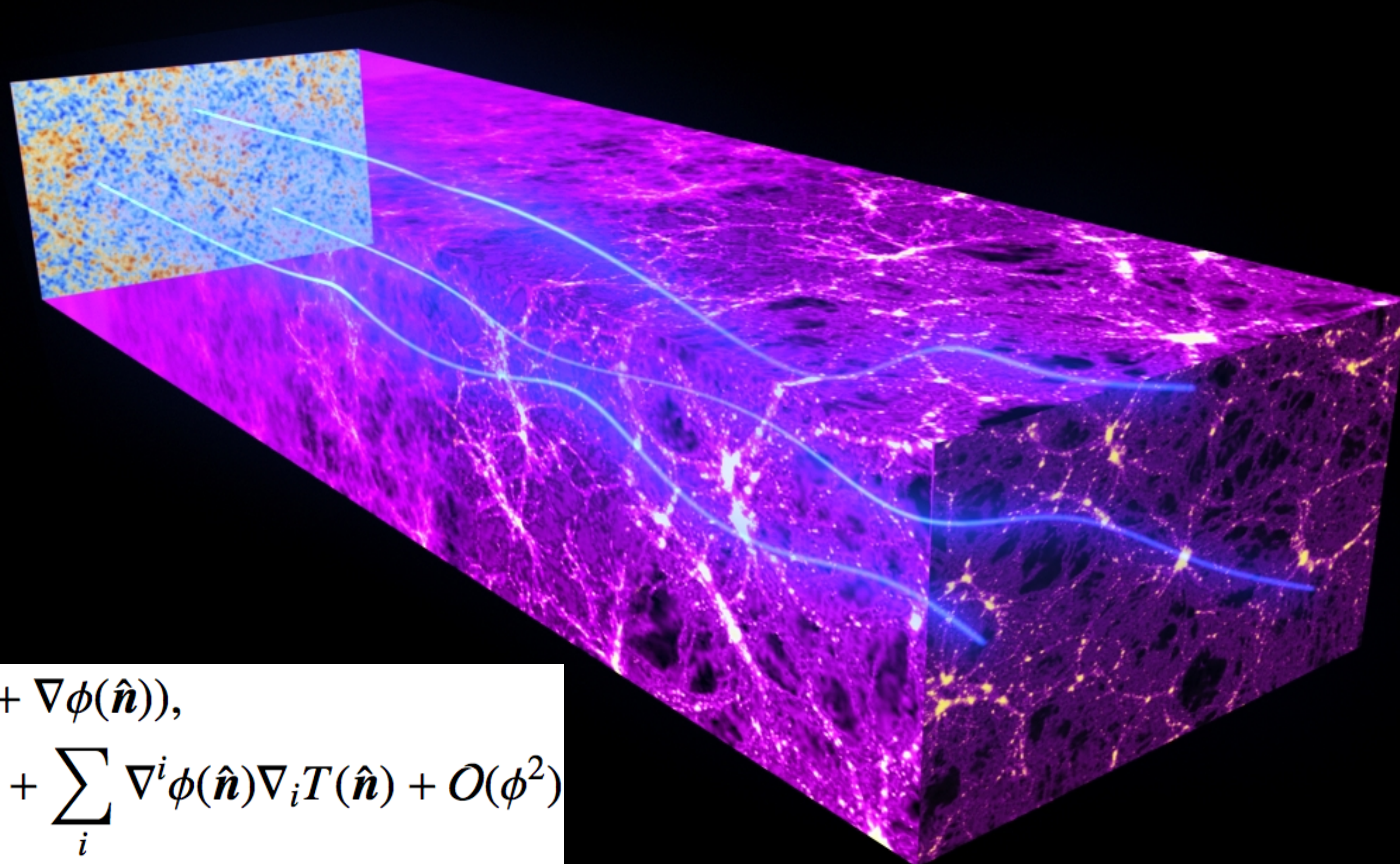
- $H0 = 67.3 \pm 1.2$ km/s/Mpc
- Difference with WMAP comes from large matter content preferred by Planck
- Tension at 2.5 σ between Planck and Cepheids or SNIa measurements



Planck versus supernovae Ω_m values



Gravitational lensing (I)



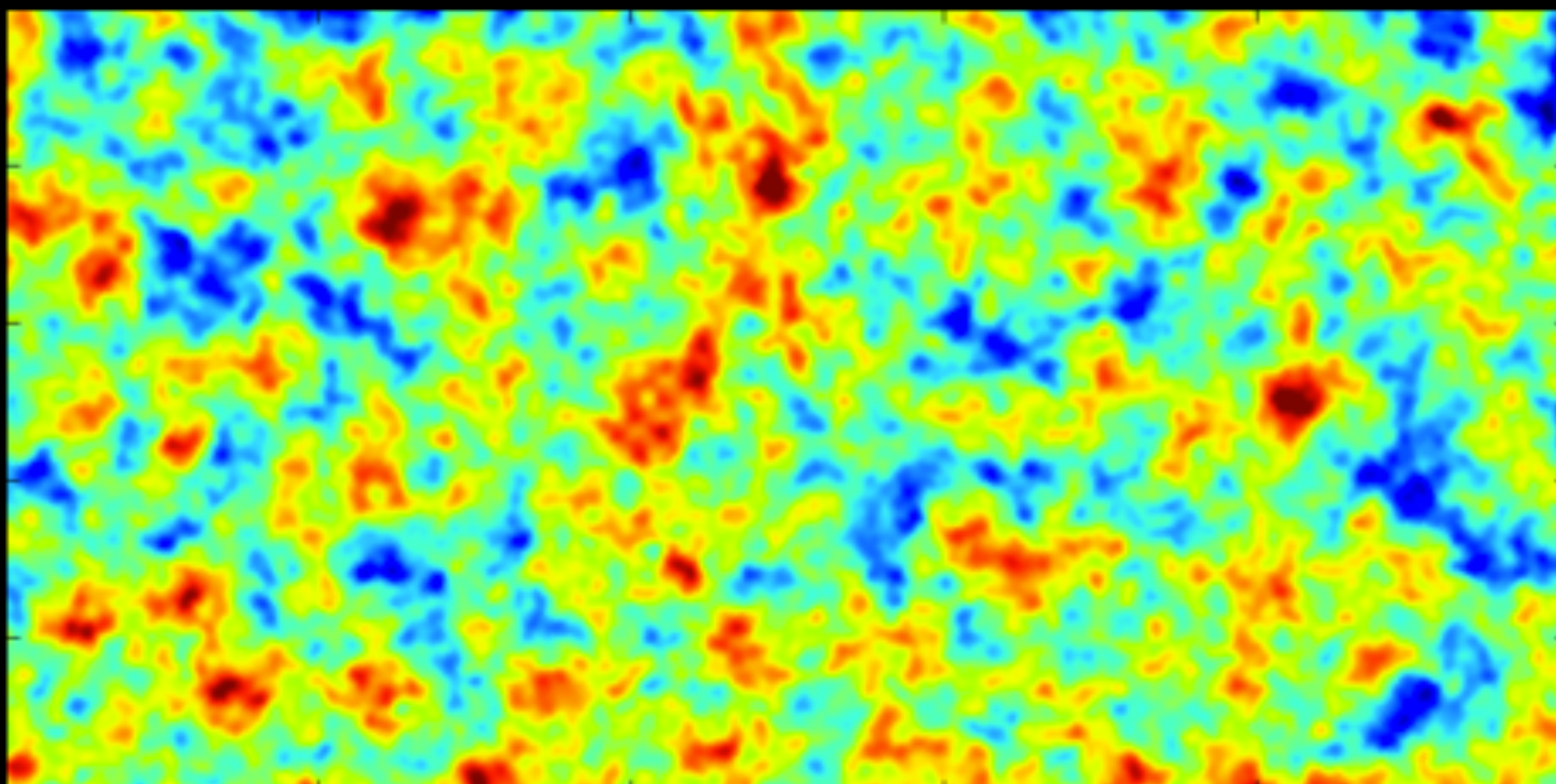
$$\begin{aligned} T(\hat{\boldsymbol{n}}) &= T^{\mathrm{unl}}(\hat{\boldsymbol{n}} + \nabla\phi(\hat{\boldsymbol{n}})), \\ &= T^{\mathrm{unl}}(\hat{\boldsymbol{n}}) + \sum_i \nabla^i\phi(\hat{\boldsymbol{n}})\nabla_i T(\hat{\boldsymbol{n}}) + O(\phi^2) \end{aligned}$$

Gravitation bends the path of light through matter between last scattering surface and us.

This lensing effect distorts the CMB map.

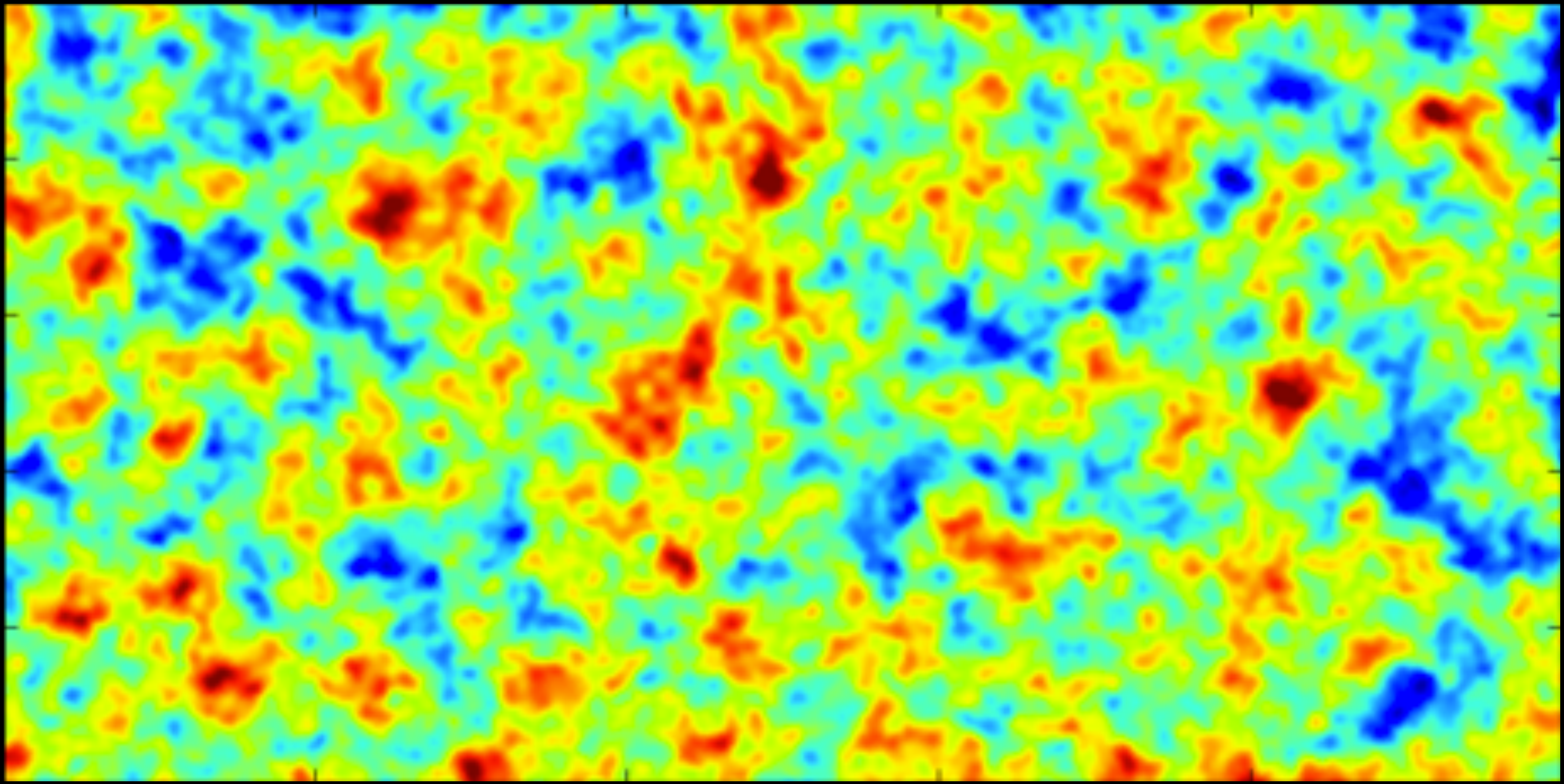
Gravitational lensing (2)
Lensing simulation

Map before gravitational lensing



Gravitational lensing (3)
Lensing simulation

Map after gravitational lensing



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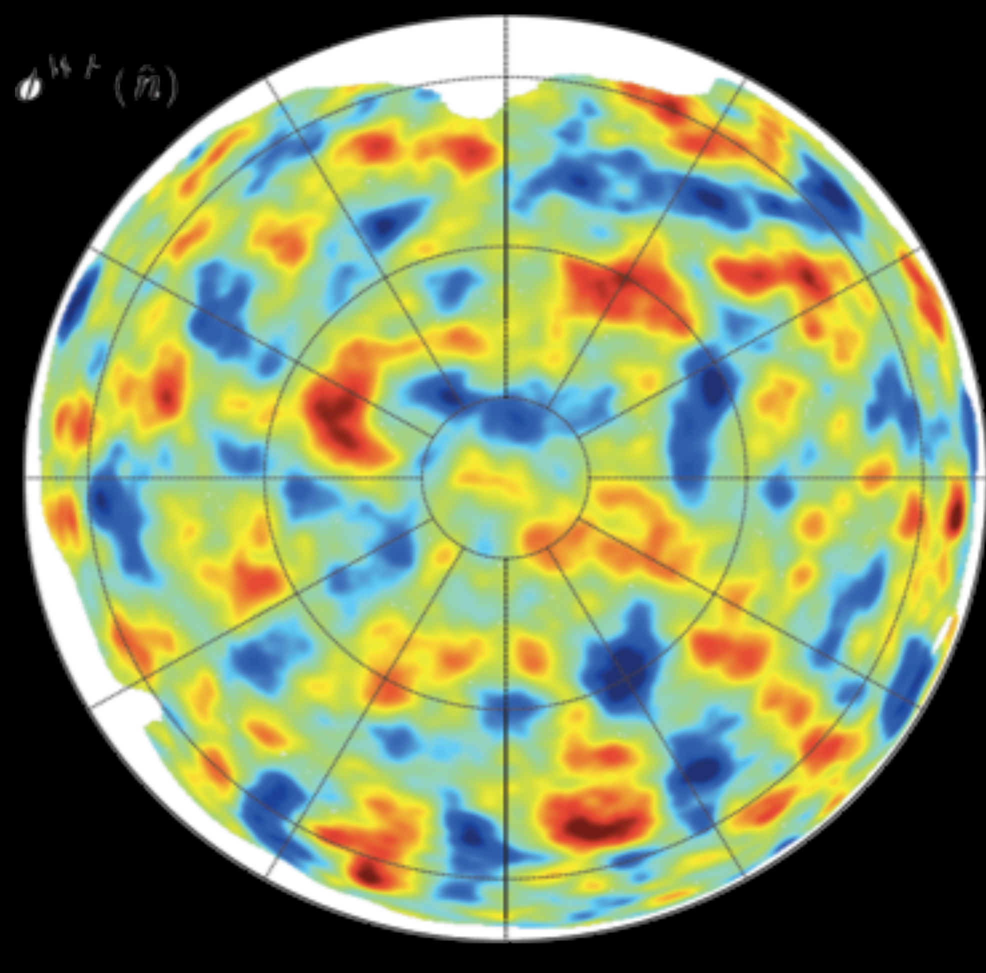
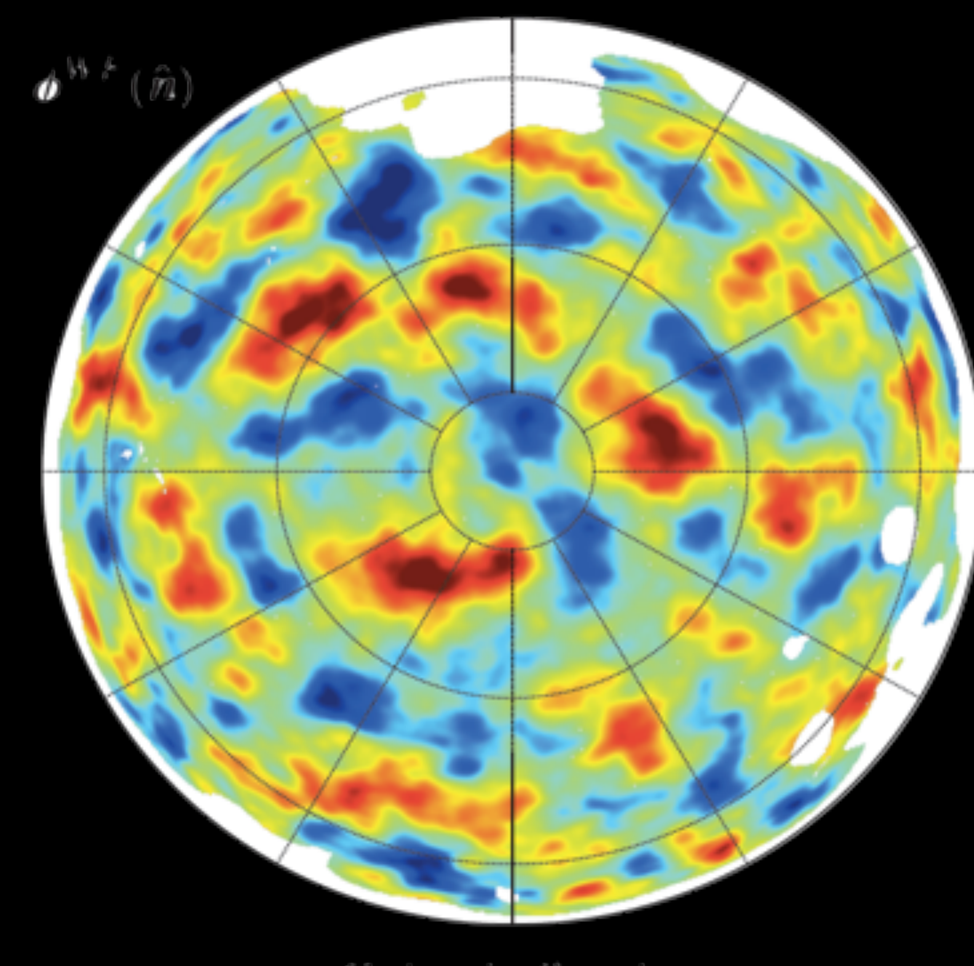
Gravitational lensing (4)
Reconstructed map

- Distribution of matter (dark + baryon) reconstructed from gravitational lensing effect

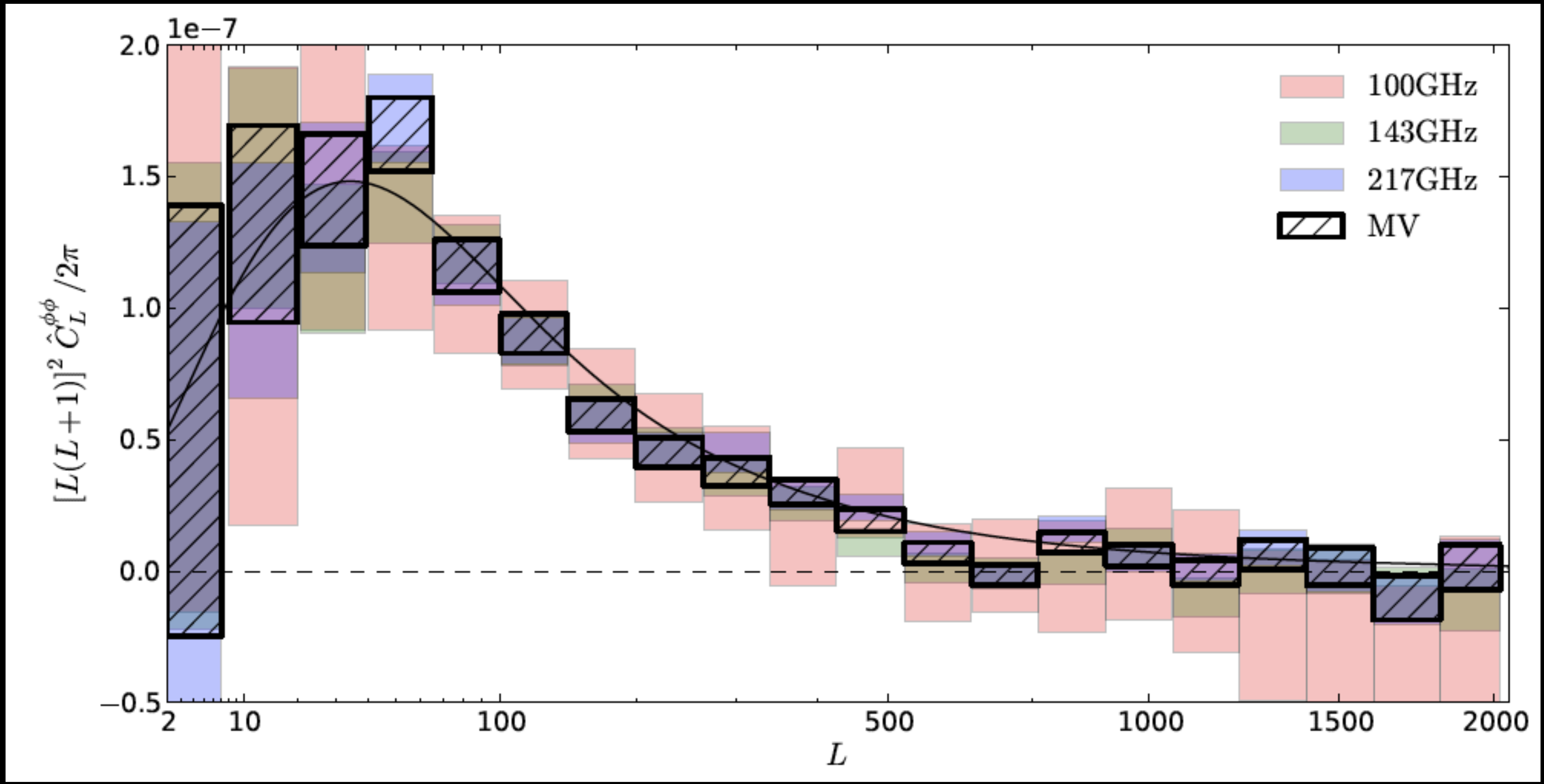


North galactic hemisphere



South galactic hemisphere

Gravitational lensing (5)
Power spectrum of lensing potential



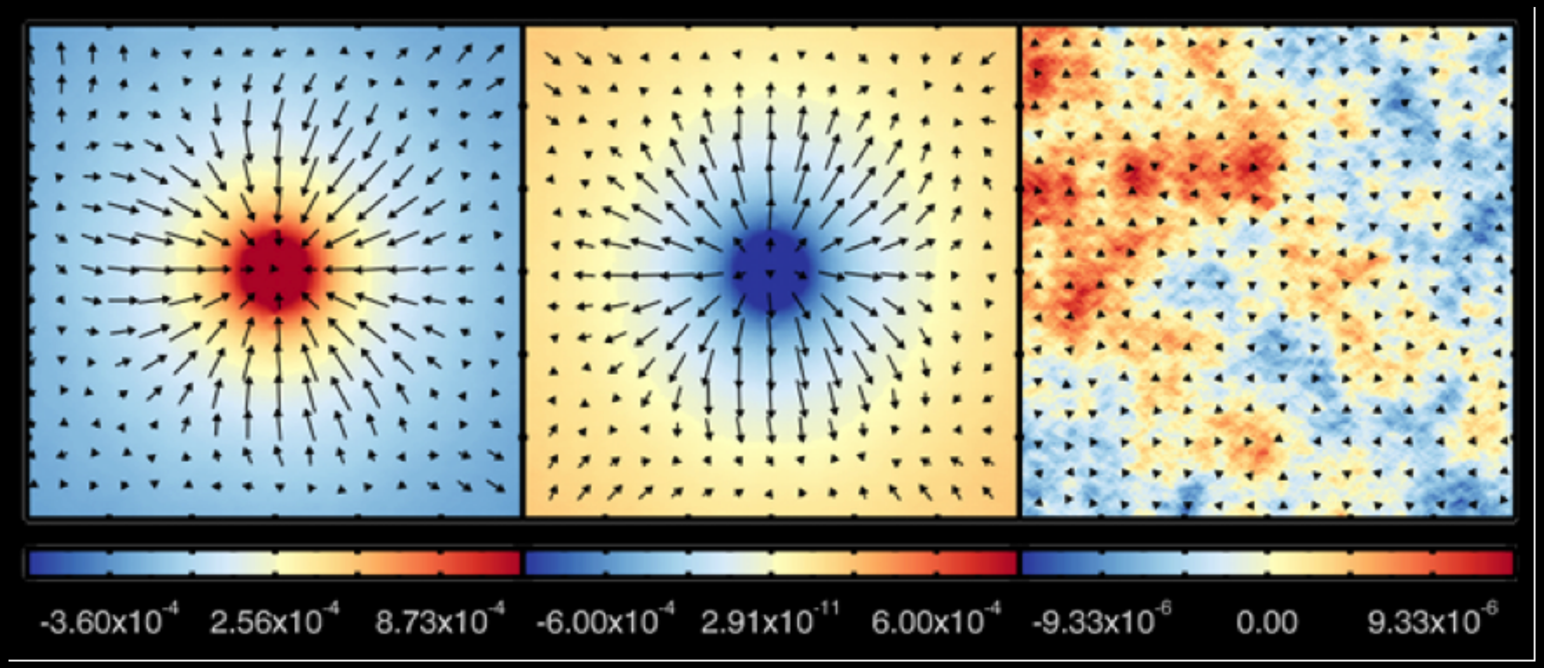
The black line is the prediction using cosmological parameters from CMB alone

Gravitational lensing (5)

CIB (cosmic infrared background) × Lensing Potential

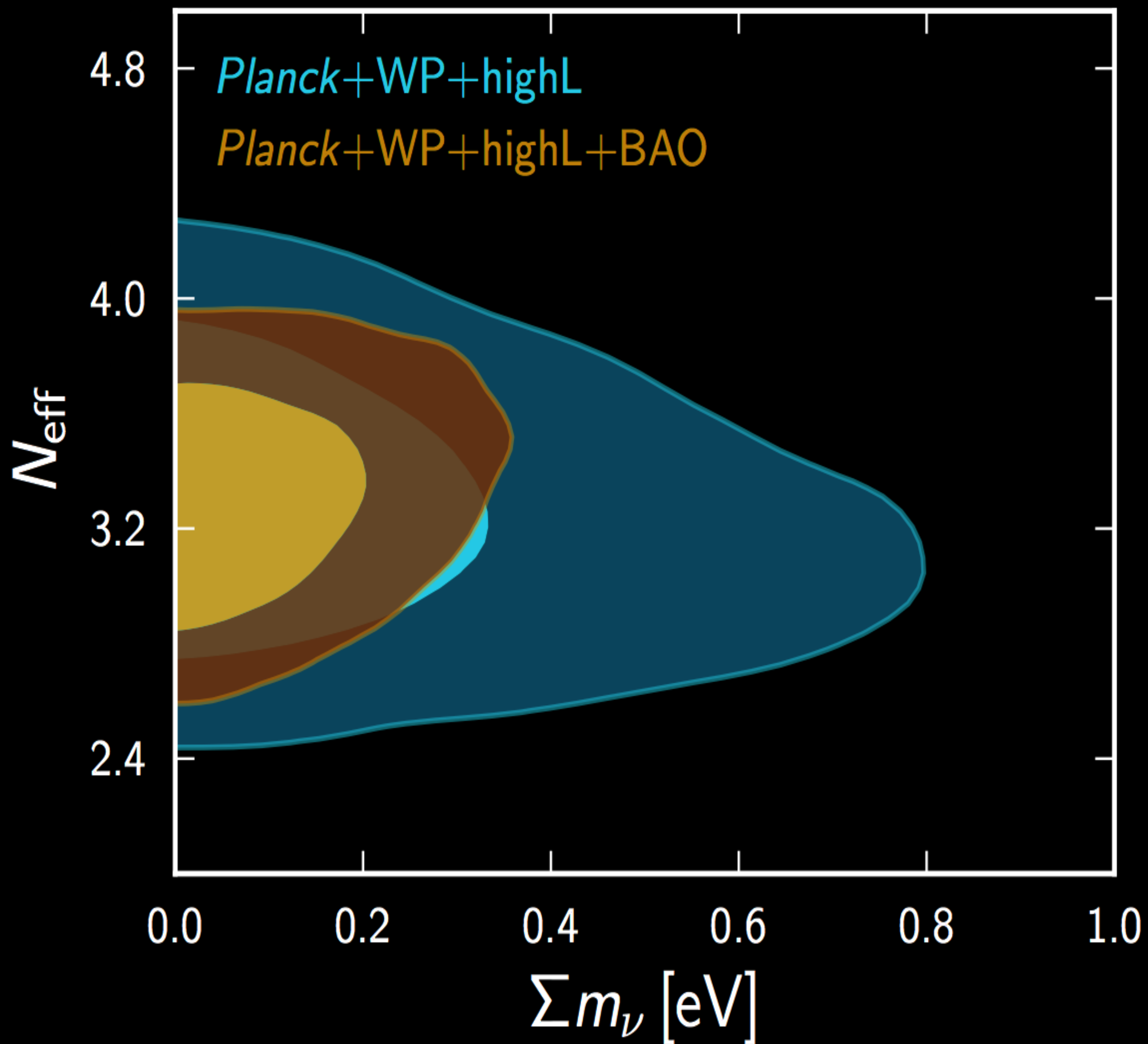
- The CIB is the remnant of star formation, much around z~2
- This material lenses the CMB
- A cross-correlation shows this:

545 GHz × Φ



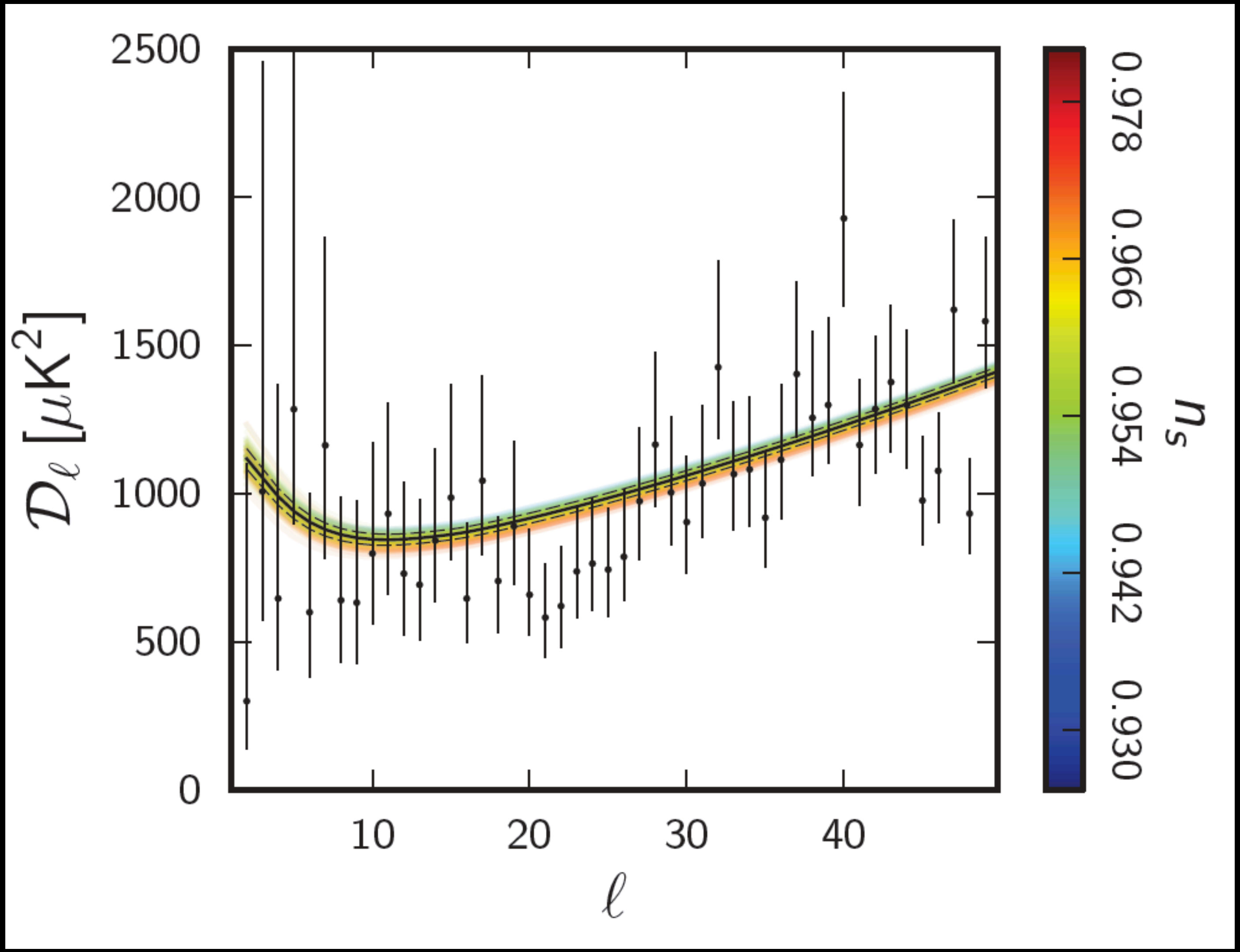
- Correlations can also be done with your favorite catalog of sources, or other tracers of mass

Mass and number of neutrinos



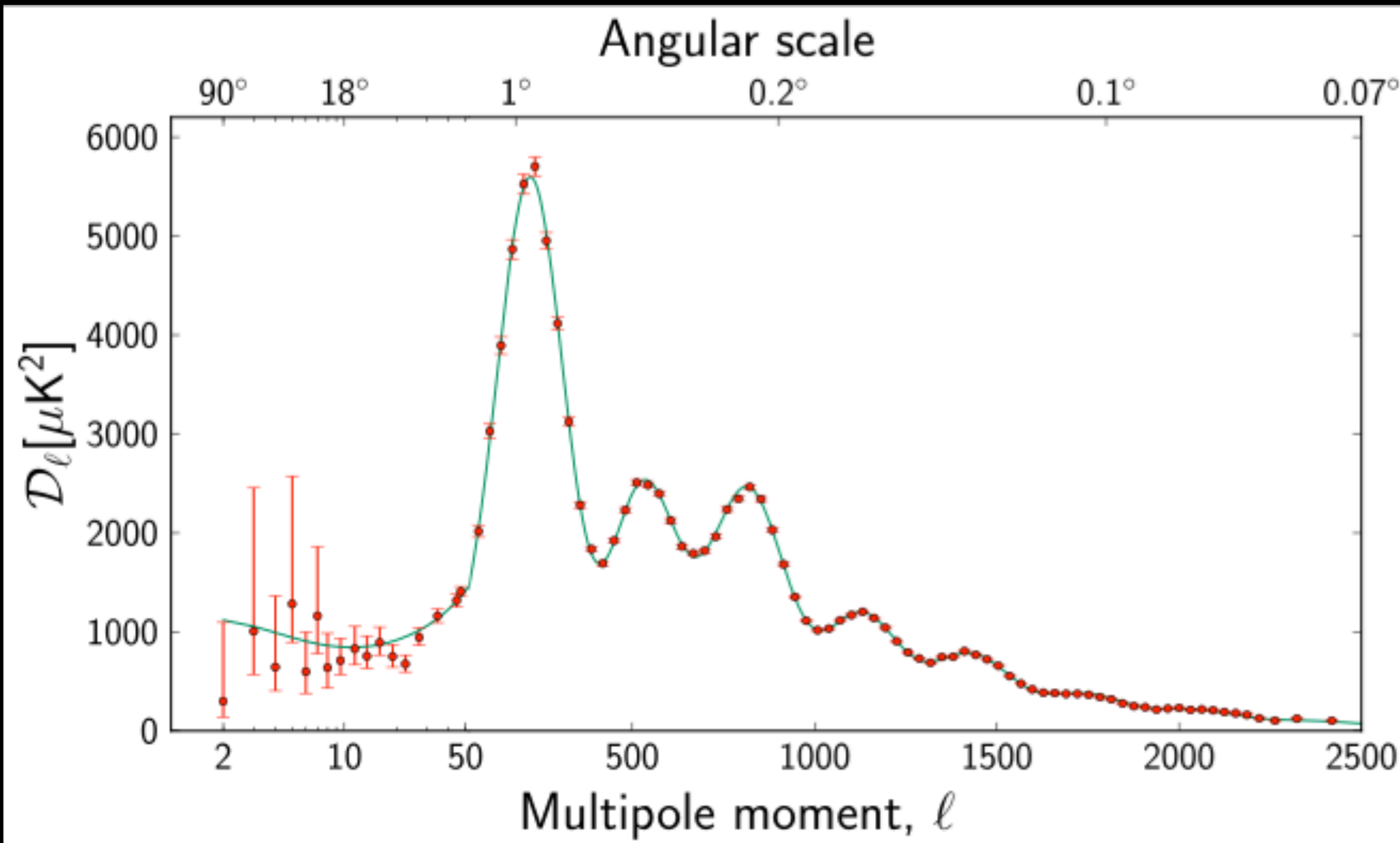
- much of this is from lensing and in conjunction with BAO
- $\Sigma m_\nu < 0.23$ eV
- $N_{eff} = 3.3 \pm 0.27$

Large scale anomaly (I)



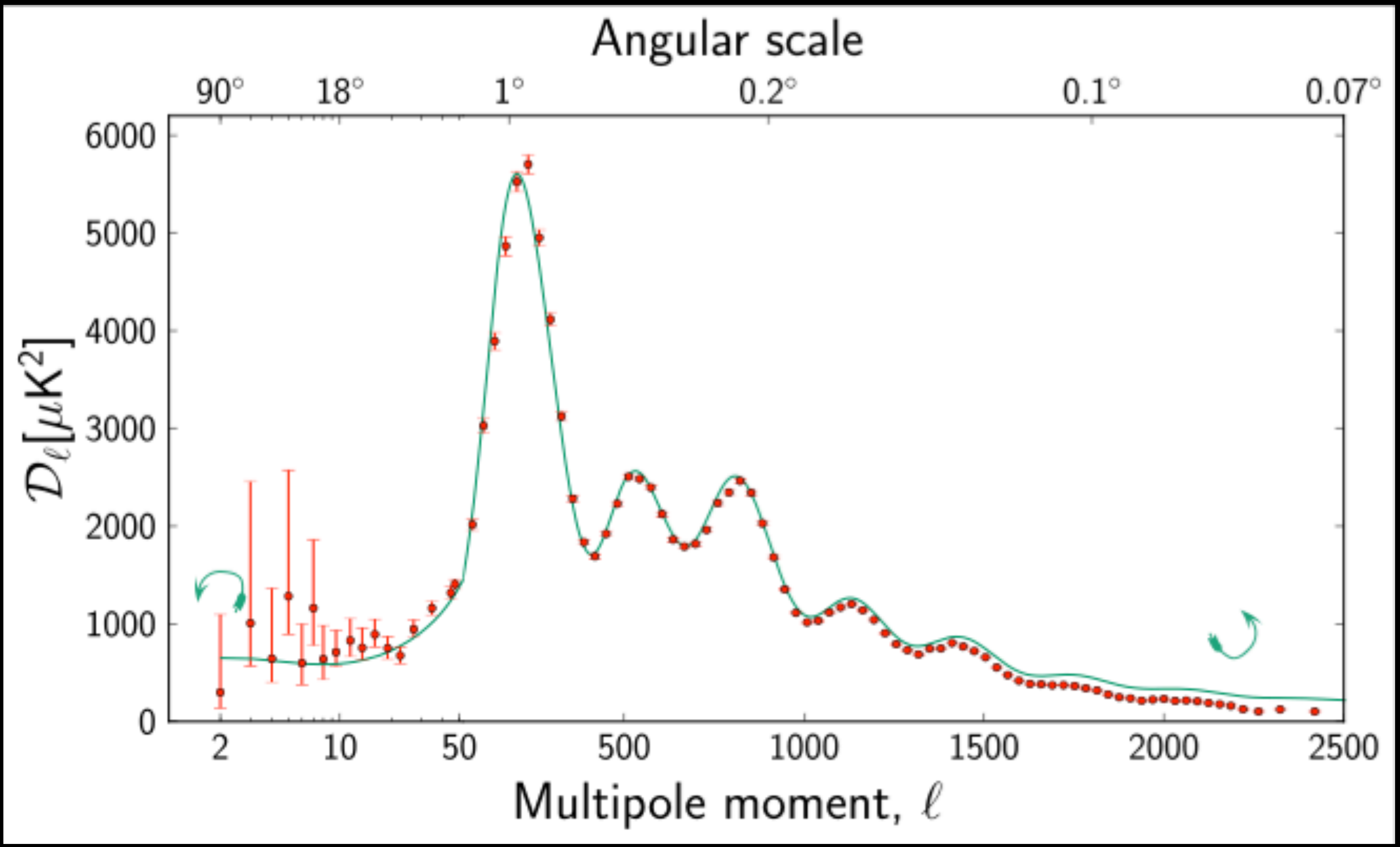
- The first 30 modes measured are lower than expected from the model
- Probability of 1% to happen...

Large scale anomaly (2)



First cosmological results from Planck

Large scale anomaly (3)



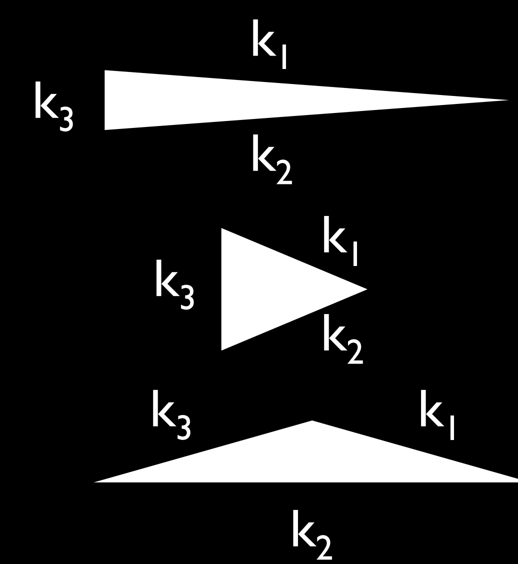
First cosmological results from Planck

Tests on the gaussianity of the CMB signal

- the simplest inflation model predicts undetectable non gaussianity contrary to many more complicated inflation models
- the bispectrum from 3 point correlations can be characterized by 3 f_{NL} factors, computed on a HFI only map

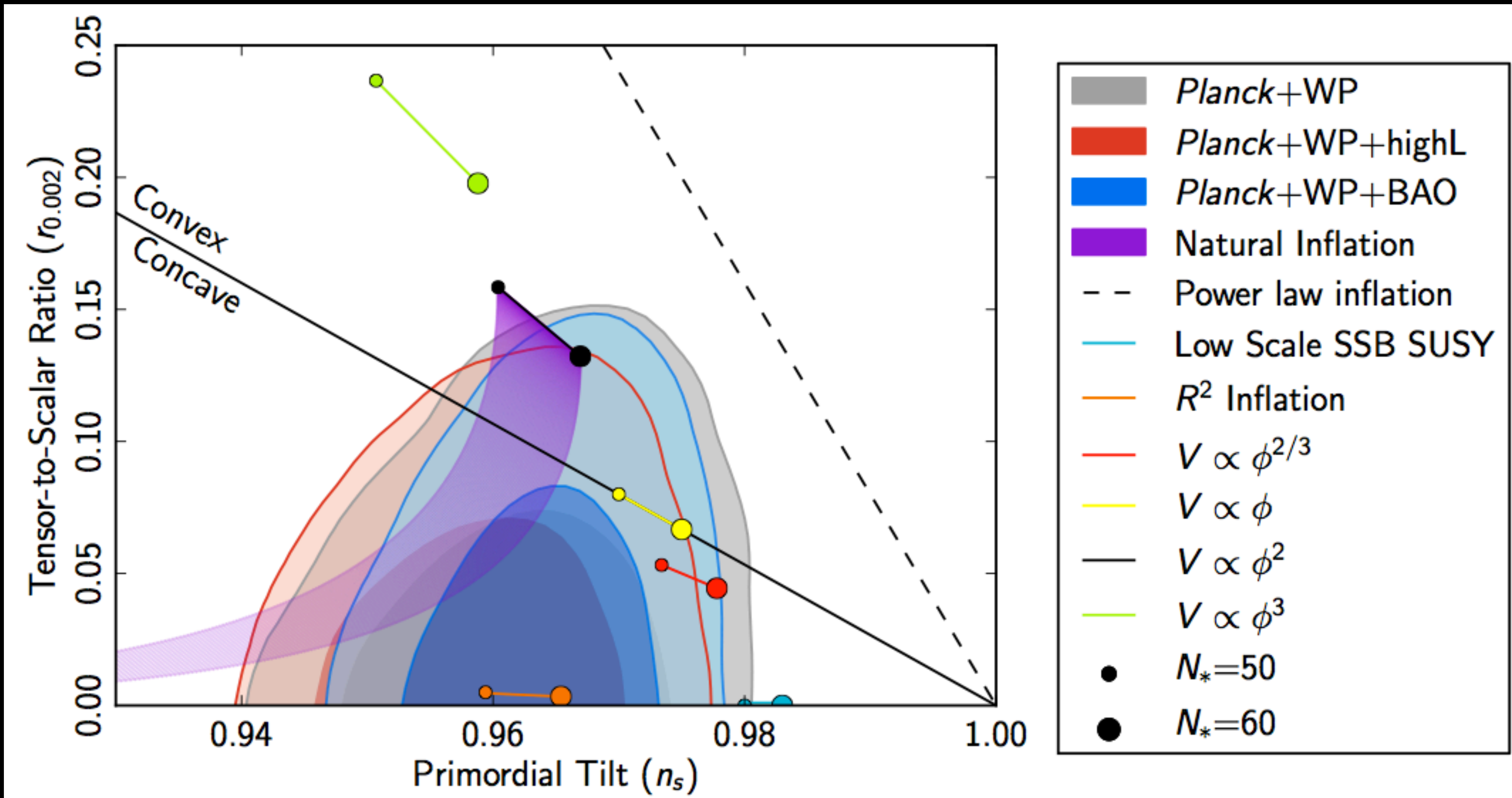
We don't see anything we "shouldn't" see

	Planck	WMAP
➢ local	2.7±5.8	37±20
➢ equilateral	-42±75	-51±136
➢ orthogonal	-25 ±39	-245±100



- Simple Λ-CDM works but Planck primordial non-Gaussianity upper limits also constrain inflation models beyond the single field slow roll

Constraints on inflation



- Exponential potential, monomial potential of degree n>2, simplest hybrid model (SB SUSY) do not fit well the data
- Planck B mode polarization sensitivity can detect r down to 0.05 and put a 3 sigma upper limit at 0.03 if we get to the noise limit (Efstathiou & Gratton)

CONSTRAINING INFLATION MODELS
by using the n_s measured value and the upper limit put on r = T/S

- Start with a generic approach proposed by *V. Mukhanov* based on a hydrodynamical description of the quantum perturbations during inflation. (astro.arxiv: 1303.3925)
- Hypotheses:
  - A single inflaton field,
  - $w = P/\rho_E$ starts with a value just above -1 and grows smoothly. Its evolution as a function of the number of e-folds is described by the following phenomenological expression which contains only 2 parameters (α and β):

$$w = -1 + \beta/(N+1)^{\alpha}$$

where N is the number of e-folds: $N = \ln(a/a_{initial})$

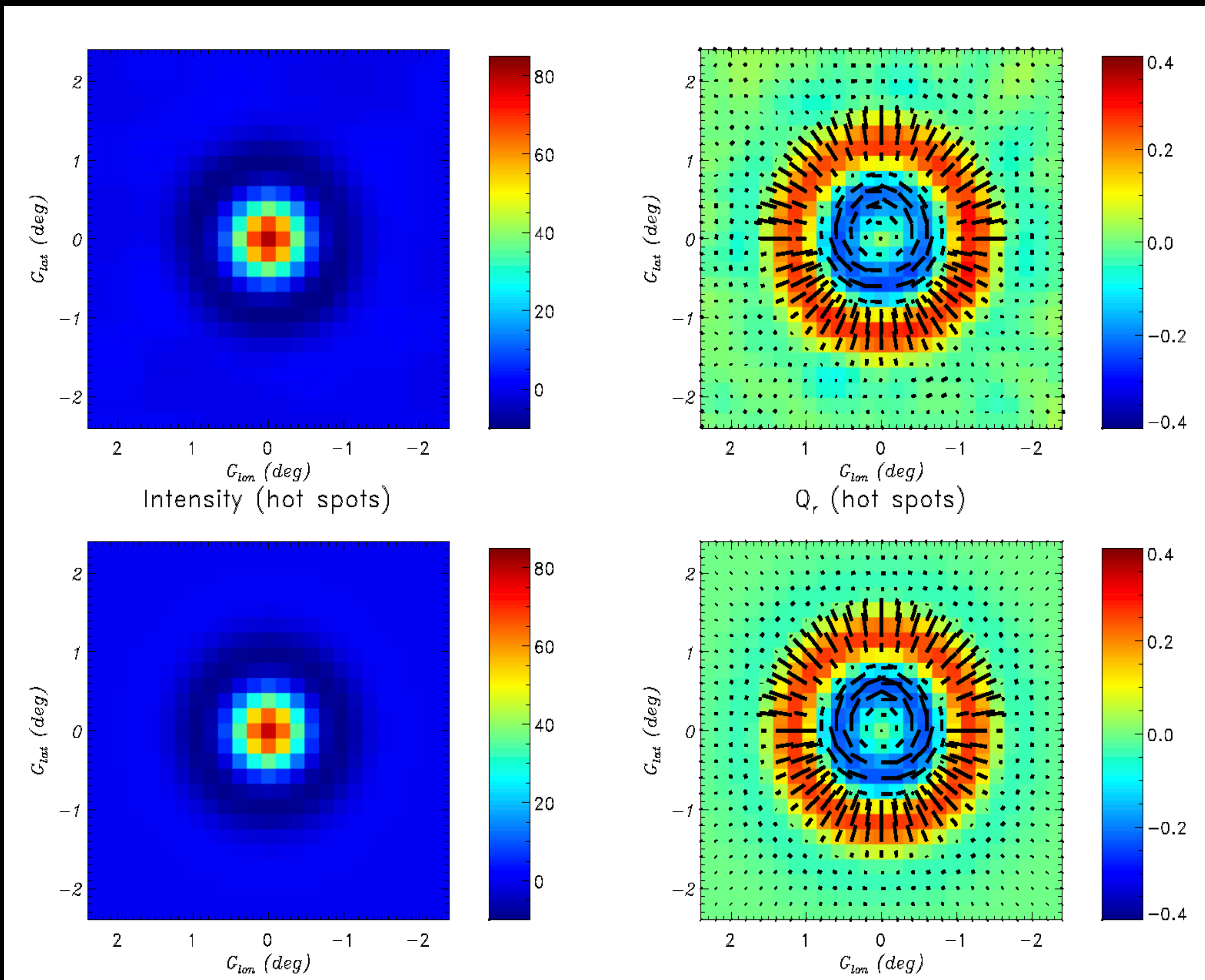
–> $n_s = f(\alpha, \beta, N)$ and $r = g(\alpha, \beta, N)$

Planck results: $3.4\ 10^{-2} < n_s - 1 < 4.8\ 10^{-2}$, $r < .26$ (allowing for n_s running)

–> $1 < \beta < 2$ assuming $.3 < \alpha < 2.5$ and $N \sim 50$ to 60.

IF Planck limit on r_s goes down to $3\ 10^{-2}$, then there is almost no room left for the β parameter.

Polarization around hot spots

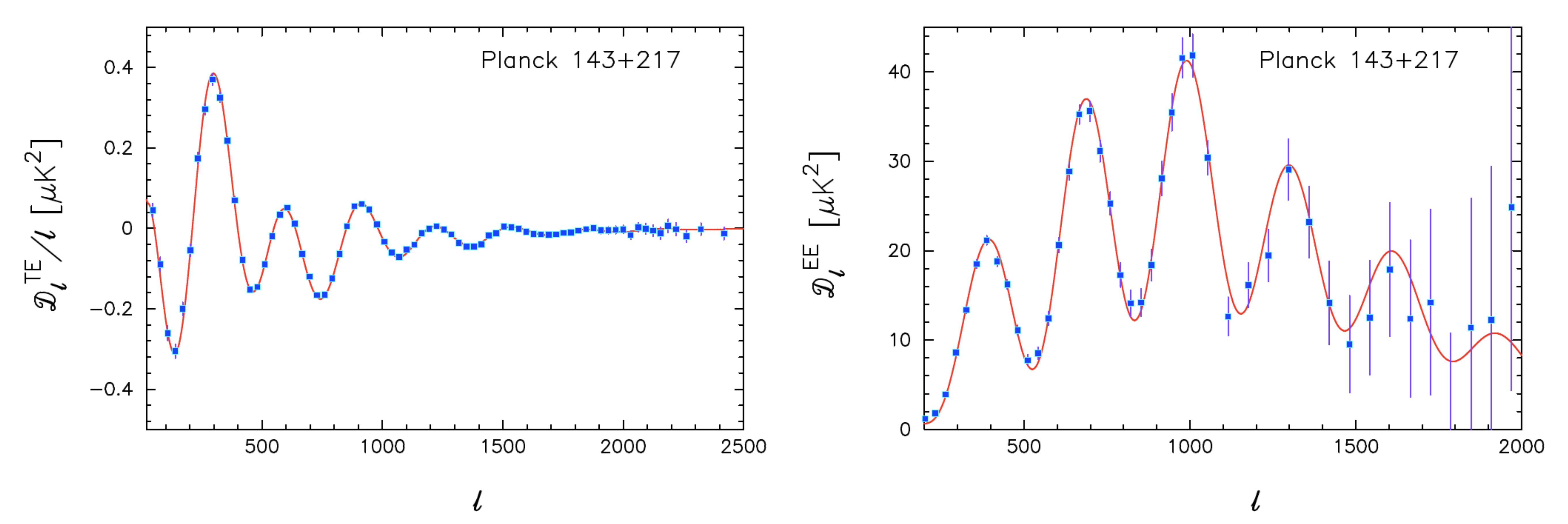


Data (top) versus expectation (bottom)

➔ Planck "sees" precisely the dynamics of fluctuations, at ~380 000 years

Planck polarization spectra

ΛCDM model fitted on temperature data only



Summary

- Planck instruments and scanning strategy allows wide range of consistency tests which give confidence in the robustness of the measurements
- Excellent agreement of T power spectrum with Λ-CDM and simplest inflationary models
- Increased precision on cosmological parameters:
  - H_0 value slighlty shifted, increase of Ω_m and decrease of Ω_Λ
  - No evidence of additional family of neutrinos: Neff = 3.3 ± 0.27
  - Limits on total mass of neutrinos: $\Sigma m_\nu < 0.23$ eV
  - No evidence for running spectral index
  - No detection of non-gaussianity, but stricter constraints

Next data release (mid-2014) will include improvements in the analysis (better understanding of the instruments and polarization) esa

planck

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